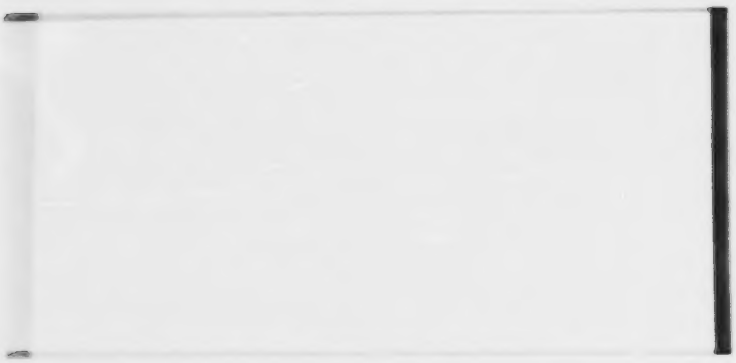

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Close Range Acoustic Ice Hazard Detection

Phase II

Volume I: Final Report

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17. Abstract

An evaluation of sonar as a means of detecting icebergs in open and ice-covered waters was undertaken during July 1986 in the Lancaster Sound/Baffin Bay regions of the Canadian Arctic. For this purpose, a specially calibrated C-Tech CDS-40A 36 kHz fish-finding sonar, mounted in the hull of the icebreaking freighter M.V. ARCTIC, was used to obtain acoustic data on the icebergs and the environment. Detection ranges up to half a nautical mile were observed for open-water icebergs (limited by downward refracting propagation conditions), and of up to one nautical mile for ice-locked icebergs (limited by the sonar characteristics). Echo measurements from icebergs ranging in mass between 300 tonnes and 2 million tonnes confirm the phenomenological relation between average acoustic target strength and estimated mass discovered during the previous work cited above. Under-ice reverberation measurements revealed very low apparent surface scattering strength values (<50dB) which can be interpreted in terms of propagation conditions and geometry. Propagation modelling showed the real possibility of extending the open water detection to the first convergence zone, which for conditions encountered during the tests has a 2 km extension at a range of some 5 km from the ship. Sonar self-noise during icebreaking was measured to be much higher than that in open waters. The results obtained suggest that close range sonar iceberg detection is acoustically feasible, and that the detection performance can be predicted on the basis of target mass and acoustic environmental and sonar system parameters.

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17. Résumé L'évaluation d'un sonar utilisé pour la détection des icebergs en eau libre ou couverte de glace a eu lieu en juillet 1986 dans le détroit de Lancaster et la baie de Baffin. Un sonar de pêche C-Tech CDS-40A fonctionnant à la fréquence d'émission de 36 kHz, convenablement étalonné et monté dans la coque du cargo brise-glace N.M. ARCTIC, a été utilisé pour obtenir des signatures acoustiques des icebergs et de leur environnement immédiat. On a réalisé des portées de détection atteignant un demi-mille marin dans le cas des icebergs en eau libre (portées limitées par le phénomène de réfraction vers le bas) et un mille marin lorsque les icebergs étaient pris dans les glaces (portées limitées par les caractéristiques du sonar). Les mesures faites des échos renvoyés par des icebergs de masse allant de 300 a 2 millions de tonnes ont confirmé la relation phénoménologique existant entre les intensités moyennes des échos et la masse estimée, relation mise en evidence lors des travaux antérieurs. La mesure de la réverbération sous les glaces a mis en évidence des valeurs très faibles de rétrodiffusion par la surface (inférieures a 50 dB), que l'on peut interpréter comme étant dues à des conditions de propagation particulières et à la géométrie de la surface. La modélisation de la propagation des ondes sonores a montré qu'il est bel et bien possible d'élargir la portée en eau libre jusqu'à la première zone de convergence, ce qui, dans les conditions propres aux essais, signifie une portée étendue a 5 km par rapport à la source d'émission, soit un gain de 2 kilometres. Le bruit propre du navire avancant dans les glaces a atteint des valeurs beaucoup plus élevées qu'en eau libre. Les résultats obtenus portent à croire que la détection approchée des icebergs par sonar est faisable et que les distances de détection peuvent être prévues en fonction de la masse de la cible, du paysage sonore et des caractéristiques particulières du sonar.

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SUMMARY

An evaluation of sonar as a means of detecting icebergs in open and ice-covered waters was undertaken during July 1986 in the Lancaster Sound and Baffin Bay regions of the Canadian Arctic. For this purpose, a specially calibrated C-Tech CDS-40A, 36 kHz fish-finding sonar, mounted in the hull of the icebreaking freighter M.V. Arctic, was used in order to obtain acoustic data on the icebergs and the environment. The sonar trials took place during a 48-hour period on a commercial voyage of the M.V. Arctic between Nanisivik on Baffin Island and Antwerp, Belgium.

The results confirmed and extended results of previous work on sonar iceberg detection. Detection ranges up to half a nautical mile were observed for open-water icebergs (limited by downward refracting propagation conditions) and of up to one nautical mile for ice-locked icebergs (limited by the sonar characteristics). Echo measurements from icebergs ranging in mass between 300 tonnes and 2 million tonnes confirm the phenomenolgical relation between average acoustic target strength and estimated mass discovered during the previous work cited above. Under-ice reverberation measurements revealed very low apparent surface scattering strength values (<50 dB) which can be interpreted in terms of propagation conditions and geometry. Propagation modelling showed the real possibility of extending the open water detection to the first convergence zone, which for conditions encountered during the tests has a 2 km extension at a range of some 5 km from the ship. Sonar self-noise during ice breaking was measured to be much higher than that in open waters.

The results obtained suggest that close range sonar iceberg detection is acoustically feasible, and that the detection performance can be predicted on the basis of target mass and acoustic environmental and sonar system parameters.

SOMMAIRE

L'évaluation d'un sonar utilisé pour la détection des icebergs en eau libre ou couverte de glace a eu lieu en juillet 1986 dans le détroit de Lancaster et la baie de Baffin. Un sonar de pêche C-Tech CDS-40A fonctionnant à la fréquence d'émission de 36 kHz, convenablement étalonné et monté dans la coque du cargo brise-glace N.M. Arctic, a été utilisé pour obtenir des signatures acoustiques des icebergs et de leur environnement immédiat. Les essais acoustiques se sont déroulés pendant 48 heures durant la traversée du N.M. Arctic entre Nanisivik sur l'île de Baffin et Anvers (Belgique).

Les résultats obtenus ont confirmé et élargi les résultats antérieurs. On a réalisé des portées de détection atteignant un demi-mille marine dans le cas des icebergs en eau libre (portées limitées par le phénomène de réfraction vers le bas) et un mille marin lorsque les icebergs étaient pris dans les glaces (portées limitées par les caractéristiques du sonar). Les mesures faites des échos renvoyés par des icebergs de masse allant de 300 à 2 millions de tonnes ont confirmé la relation phénoménologique existant entre les intensités moyennes des échos et la masse estimée, relation mise en évidence lors des travaux antérieurs. La mesure de la réverbération sous les glaces a mis en évidence des valeurs très faibles de rétrodiffusion par la surface (inférieures à 50 dB), que l'on peut interpréter comme étant dues à des conditions de propagation particulières et à la géométrie de la surface. La modélisation de la propagation des ondes sonores a montré qu'il est bel et bien possible d'élargir la portée en eau libre jusqu'à la première zone de convergence, ce qui, dans les conditions propres aux essais, signifie une portée étendue à 5 km par rapport à la source d'émission, soit un gain de 2 km. Le bruit propre du navire avançant dans les glaces a atteint des valeurs beaucoup plus élevées qu'en eau libre.

Les résultats obtenus portent à croire que la détection approchée des icebergs par sonar est faisable et que les distances de détection peuvent être prévues en fonction de la masse de la cible, du paysage sonore et des caractéristiques particulières du sonar.

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Canadian Astronautics received outstanding support from the officers and crew of the MV Arctic during all phases of the program. During the trials, the difficult and often unusual manoeuvres of the vessel were undertaken with a spirit of cooperation from the bridge which resulted in the successful completion of all the major program objectives.

The efforts of Pietro de Bastiani from Canarctic, of Brent Broughton from Norland Science and Engineering and of Nick Van Beek from C-Tech were key elements in the success of the trials.

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1.0 INTRODUCTION

1.1 GENERAL COMMENTS

Safe navigation in Arctic waters has always presented a major problem to mariners. The presence of ice and icebergs demand the utmost vigilance on the part of ship's personnel. The increase in shipping activity expected in the next few decades, particularly with the transportation of hydrocarbons, coupled with the realization by commercial and government bodies that the marine environment is an important natural resource means that technological advances that may reduce the risk of collision should be evaluated. From a commercial viewpoint, the overall desire to find the quickest and safest route through Arctic waters results from economic considerations. Additional reasons driving the interest in safe Arctic navigation include both defense and Canadian sovereignty considerations, both of which have received abundant media coverage over the last few years.

At present, visual observation and radar are the traditional methods of detecting obstacles at sea. Radar systems have reached a relatively sophisticated stage but have certain limitations with respect to close range small targets and inclement weather and sea conditions. For example, most shipborne radars have rather poor short range detection characteristics. Further, for targets near the sea surface the clutter return is very large due to the large grazing angles. In the case of icebergs, approximately 9/10's of their mass is below the water line and thus, invisible to radar. Certain icebergs exhibit a low profile and have an illuminated face gently sloping away from the radar. Such conditions seriously affect the detectability of these icebergs by radar even at close ranges. In addition, the radar detection of small icebergs in the midst of sea ice is often very difficult in view of the time stationary returns caused by ice pieces or surface features.

Sonar, therefore, has been considered as an alternative methodology for remote iceberg detection for the following reasons:

1. Sonar operates within a communication channel which is totally separate from marine radar. It can be considered as an adjunct to radar thereby reducing the probability of missed targets.

2. The major portion of an iceberg is below the water line and, therefore, potentially a better target for remote detection using sonar.

The use of sonar in this role is not without problems. Until recently, little information* concerning icebergs as individual sonar targets existed in the public domain. Also, near-surface horizontal acoustic propagation in the ocean is subject to refraction phenomena and the effects of waves and turbulence. From an engineering perspective, the installation and eventual deployment of a sonar transducer system within the bow area of an icebreaking hull is a difficult mechanical problem. Finally, the detection of iceberg echoes over the acoustic background resulting from ice breaking is a difficult problem. Therefore, programs which attempt to address the above aspects are important in that they provide useful basic design information concerning the feasibility and practicality of using sonar for iceberg detection.

1.2 PHASE I: PROOF OF CONCEPT WORK: 1984-1985 PROGRAM

The transportation Development Centre of Transport Canada contracted Canarctic Shipping Company Limited to undertake and manage a program to evaluate the potential of using a sonar as a means for close range ice hazard detection. In turn, Canarctic sub-contracted Canadian Astronautics Limited to carry out the program using a sonar sysem installed in the ice breaking vessel M.V. Arctic.

In Phase I, the original approach was selected on the basis of practicality and available funding. The tests were conducted during a three-day period allocated during a normal commercial voyage of the MV Arctic. The tests specifically addressed the acoustic aspects of ice hazard detection in open water, as these were judged to be easier and quicker to solve than the mechanical aspects of transducer installation. The measurements were made by using an inexpensive commercial fish-finding sonar, (C-Tech's CDS40-A) adapted to give calibrated output levels, along with appropriate ice-truthing and environmental observations.

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* Information available at the time came exclusively from earlier, less than successful attempts at proving/quantifying sonar iceberg detection. See Horton et al 1966 and Remote Applications 1981, in addition to the report on phase I of this work.

This approach proved quite successful (de Heering, Friberg, 1985) and provided a positive assessment of the sonar detection of icebergs, together with a simple phenomenological model relating the iceberg's target strength (i.e. its ability to reflect a sonar signal) to its mass. Other important sonar parameters (echo duration, detection range, etc.) were measured and explained in terms of the relevant environment data.

1.3 PRESENT WORK, PROOF OF CONCEPT PHASE II: 1985-1987 PROGRAM

Although Phase I of the work had been quite successful, it fell short of answering all the pertinent acoustical questions relating to the acoustic feasibility of sonar close-range iceberg detection. Canarctic was again contracted by TDC to pursue and manage further studies and Canarctic then tasked Canadian Astronautics to further investigate the following phenomena:

(i) Echo returns from ice-locked bergs.
(ii) Under-ice reverberation returns.
(iii) Under-ice propagation.
(iv) Ship's self-noise while transitting through ice.

The planning and preparation for this work took place in 1985 and 1986. The data acquisition was accomplished during 48 hours of dedicated ship time during one of the July passages of the MV Arctic between Nanisivik and Antwerp. Most of the work was completed while the ship was traversing the ice pack covering the northern part of Baffin Bay. The data analysis, was started on-board the ship for quality control purposes, and completed in Ottawa during the months following the test.

2.0 ICE AND ICEBERGS - PHYSICAL AND ACOUSTIC

2.1 GENERAL DESCRIPTION*

Icebergs and sea ice represent the major hazard to Arctic navigation. Most icebergs found off eastern Canada calve from the glaciers on the south and west coasts of Greenland and drift north in the West Greenland Current. The icebergs often remain in the Baffin Bay region for several years before heading south along the Labrador coast under the influence of the Labrador Current. Since icebergs are continually melting due to the action of waves and increases in water and air temperatures, they naturally change shape. This melting process is non-uniform. Therefore, icebergs periodically become unstable and either roll or break up into smaller pieces. Icebergs can range in size from ice pieces several metres in length to icebergs with dimensions in excess of 200 metres and masses greater than 10 million tonnes. Maximum keel depth of these very large icebergs can exceed 200 metres. On the other hand, sea ice is formed by the freezing of the ocean and can form ridges with sail heights up to 20 metres and draughts in the order of 40 metres. On melting, these ridges break up and become small hazards. In the absence of ridging, first year sea ice thickness seldom exceeds two to three meters. Generally speaking, multiyear sea ice presents a greater hazard to navigation as it is harder and, often , thicker than first year ice.

As icebergs drift into shallow water, they often become grounded and can remain stationary for long periods. Eventually, when suitable conditions prevail, they will move off and continue their course. Both icebergs and sea ice present a threat to safe navigation in Arctic waters.

2.2 ICEBERG TYPES

The International Ice Patrol has a classification scheme that groups icebergs into shape and size categories based on their above water

*The material presented in this chapter is an edited version of material presented earlier (see de Heering et al, 1985 Final Report) taking into account progress achieved in the intervening period.

dimensions. This classification scheme is given in Table 2.1 along with approximate details on the sizes of typical icebergs in each category. It is used by most ice observers and interested parties for recording iceberg details. Of great interest to commercial organizations, in particular oil companies with drilling programs in Arctic areas, are estimates of mass and the maximum depth of the keels. Using presently available technology, measurement of above water dimensions of icebergs under normal conditions is reasonably accurate but underwater measurements on a routine basis are subject to gross uncertainties. Estimates of iceberg mass are relatively easy if volume is known (see Appendix I). Iceberg volume is easily obtained from accurate above water dimensions and/or three-dimensional photography, albeit at some cost. However, every iceberg has a unique underwater shape and thus far, routine mapping of underwater shape is not economically viable. Nevertheless, over the last few years, several research programs mainly in support of oil drilling activities have used sidescan sonar technology to provide the underwater shape of icebergs. Klepsvik and Fossum (1980) have described the method commonly used for this work and Lowry et al. (1979) and Benedict and Hall (1979, 1980) have reviewed most other sonar techniques. Figure 2.1 is an example of two vertical underwater profiles taken of a large iceberg off Labrador. Although not to scale, the approximate underwater shape can be seen. Figure 2.2 is an interpretation of the overall shape when all data is included. These figures, presented by kind permission of Petro Canada Inc., indicate the most common features of all icebergs namely that the underwater dimensions are greater than surface measurements, that a bulge, or "indentor", exists and that the underwater shape is complex. Only in the last few years have attempts been made to produce three-dimensional maps of the underwater shape of icebergs. This research is certainly in its infancy and presently most of these data are proprietary (see Petrocan Exploration, 1983).

ICEBERG CLASSIFICATIONS TAKEN FROM INTERNATIONAL ICE PATROL GUIDELINES

ICEBERG TYPE CLASSIFICATIONS

NAME	I.D. CODE	DESCRIPTION
Blocky	BL	Steep precipitous sides with horizontal or flat top, very solid berg, length/height ratio 5:1 (approx.).
Drydock	DD	Eroded such that a large U-shaped slot is formed with twin columns of pinnalces. Slot extends into the waterline or close to it. Last stage of drydocked bergs are horned and winged.
Dome	DO	Large smooth rounded top. Solid type berg.
Pinnacled	PI	Large central spine or pyramid or one or more spines dominating the shape. Less massive than dome-shaped bergs of similar dimensions. These are also known as Picturesque "Greenland" type bergs.
Tabular	TA	Horizontal or flat-topped berg with length/height ratio of 5:1 (approx.).
Bergy Bit	BB	A mass of glacial ice smaller than berg but larger than a growler, about the size of a small cottage. Small berg or large growler is preferred usage.
Growler	GR	A mass of glacial ice that has calved from a berg or is the remains of a berg. Less than 2.5 m in height and less than 0.6 m waterline length

ICEBERG SIZE CLASSIFICATIONS

TYPE	I.D. CODE	HEIGHT	LENGTH
Tabular Bergs:			
Small	S	6 m	Less than 90 m
Medium	M	6 - 15 m	90 - 215 m
Large	L	Greater than 15 m	Greater than 215 m
Other Bergs:			
Small	S	Less than 15 m	Less than 60 m
Medium	M	15 - 45 m	60 - 120 m
Large	L	45 - 75 m	120 - 215 m
Very Large	V	Greater than 70 m	Greater than 215 m

Table 2.1 Iceberg Classification

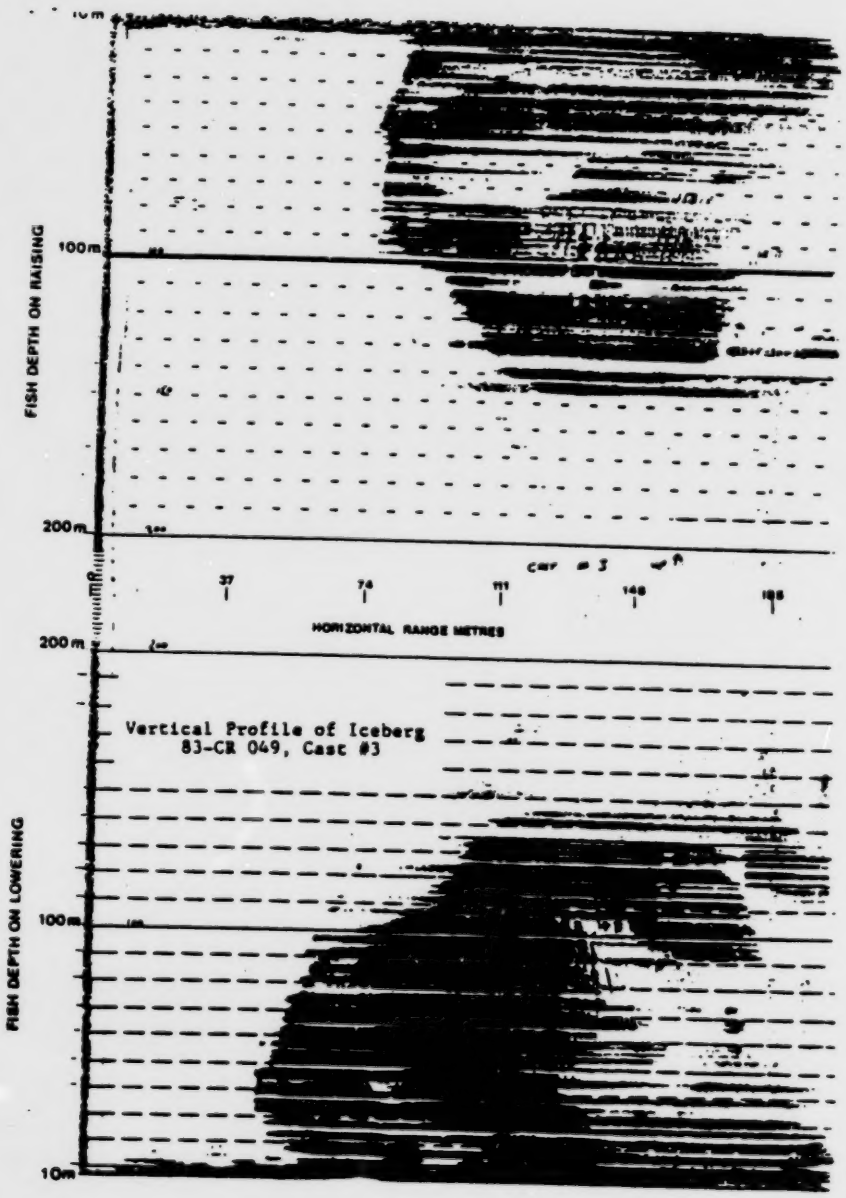


Figure 2.1 Vertical Profile of Iceberg 83-CR 049, Cast #3

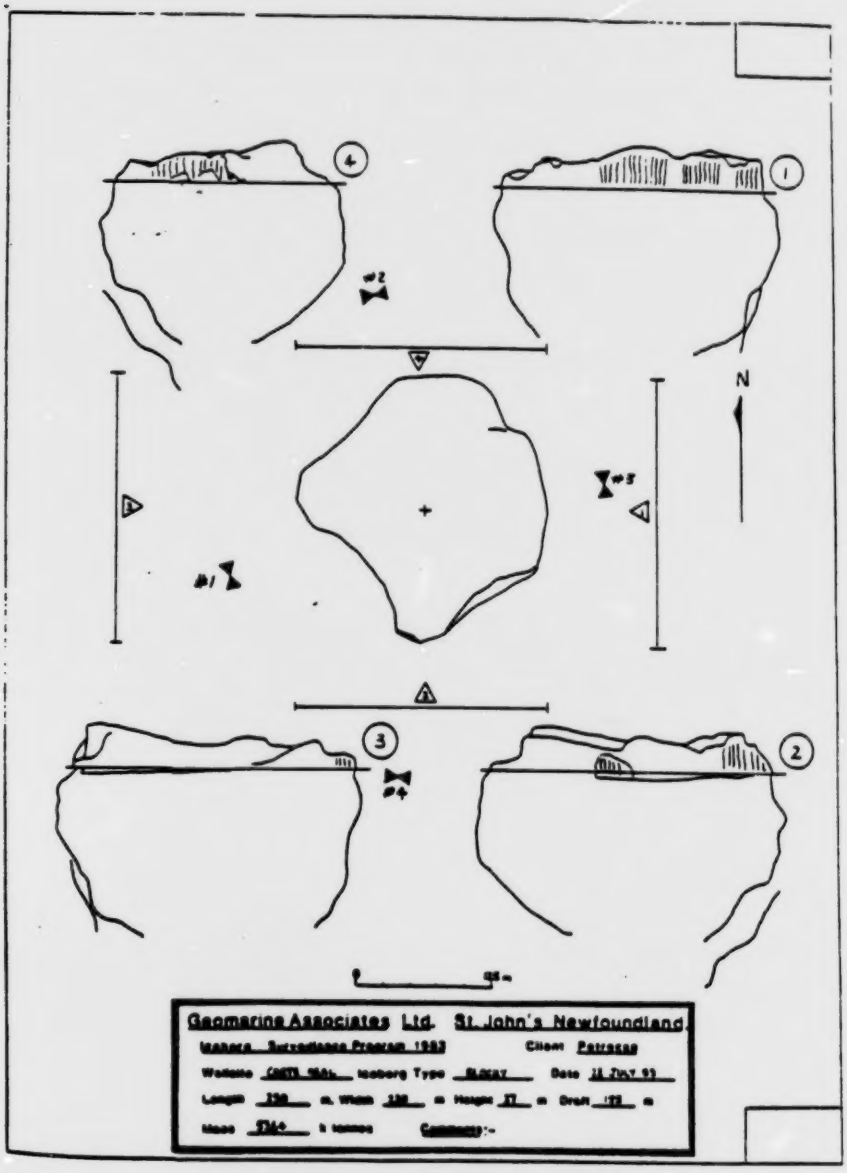


Figure 2.2 Overall Shape Interpretation

2.3 THE ICEBERG AS A SONAR TARGET

The technique of classifying underwater objects as targets has its roots in the military establishment. The physical principle on which this type of remote sensing relies is that a target insonified by a sonar beam will intercept acoustic energy and redirect it in all directions. Under normal conditions, some of this energy will be reflected back towards the source and could be detected as an echo by a suitable receiver. The time interval between the original outgoing pulse and the arrival of the echo is obviously a function of the distance between the target and the source. Since the sound speed in water is known, target range is easily calculated. The amplitude of the echo should also be expected to be some function of the amount of energy intercepted and redirected by the target. Target size, its reflecting qualities and its geometry could, therefore, contribute to echo generation. In other words, the potential exists for the amplitude of the echo to be an estimator of the physical size of the target. If icebergs were perfect geometrical shapes and transmission of acoustic energy in water were not affected by the characteristics of the medium then the relationship between echo amplitude and target size would be well controlled. However, nature is such that this situation rarely exists. Icebergs do vary considerably in shape, and convex and concave surfaces can produce defocusing and focusing zones which will have a considerable effect on echo amplitude. Also, the reflecting qualities of ice vary considerably with temperature particularly around the freezing point. Fortunately, the mass of an iceberg is such that the temperature of the ice surface is likely to be reasonably stable. All these factors will tend to mask amplitude effects due to size alone.

Another important factor that does not affect amplitude directly but must be considered in any underwater propagation problem concerns the changes in sound speed characteristics of the ocean. Changes in pressure, salinity and temperature will result in sound speed variations causing acoustic paths to refract. This has the effect of creating shadow zones even over short ranges, Urick (1975). One final propagation problem likely to be encountered is the effect of turbulence and wave action close to the sea surface. Since a ship-mounted sonar would invariably involve

transmission paths just beneath the sea surface, these effects could degrade and mask target echoes due to scattering and sea noise. Figure 2.1 shows this effect at transducer depths less than 10 metres.

The work performed under Phase I of the present program (de Heering et al 1985, Final Report) generally confirmed, the qualitative analysis presented above, for icebergs targets in open water. Two of the main results achieved (using a 36 kHz sonar) under Phase I were:

(i) Iceberg target strength (see below, Section 2.4) can be modelled, on average as being, close to that of a smooth ice sphere of mass equal to that of the iceberg. (see Figure 2.3)

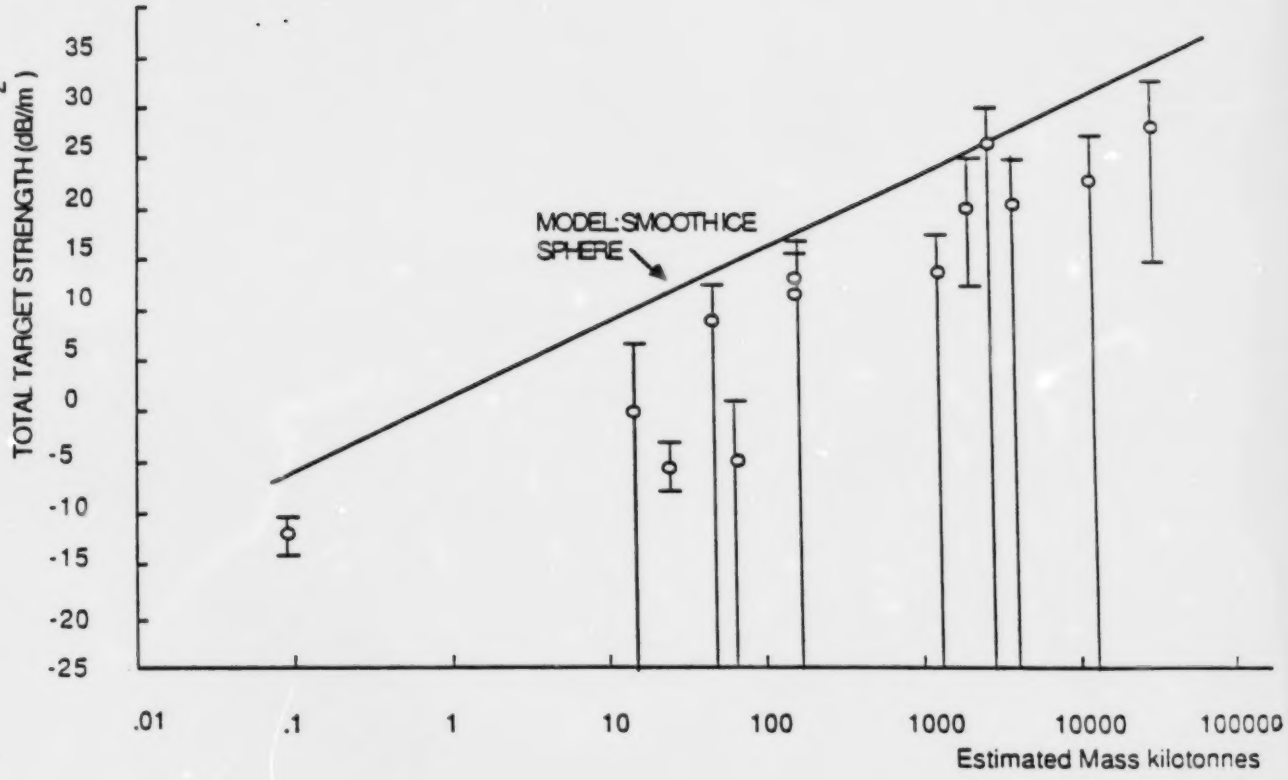
(ii) Iceberg detection range in open water can be predicted from the sonar equation taking into account ambient propagation conditions and the estimated iceberg draft.

No results were obtained at frequencies other than 36 kHz or with ice cover. However, the data collected proved sufficient to make general predictions of shipborne sonar performance for ice hazard detection in open water.

2.4 THE CONCEPT OF TARGET STRENGTH

In active sonar systems where echoes are used in a quantitative sense as well as being a range estimator, the echo amplitude has to be referred to the target object. The most common method of making this transition is to invoke a concept of target strength such that the energy contained in an echo in some way reflects a target size parameter (see eg. Urick, 1975).

This can be accomplished by referring the energy contained in an actual echo to that which would result from a target sphere of standard dimensions and composed of perfectly reflecting material. Sonar engineers typically use a reference spherical target with a radius of two metres.



TOTAL TARGET STRENGTH (MEASURED AT 36 kHz) AS A FUNCTION OF ESTIMATED MASS FOR 14 ICEBERGS, REPRESENTED IN TERMS OF MEAN AND STANDARD DEVIATION OF THE LINEAR VALUES, CONVERTED TO DECIBELS.

Ph. de Heering, D. Friberg, Proof of concept tests, data acquisition and analysis for close range ice hazard detection. Final report prepared for Canarctic Shipping Company Limited - Canadian Astronautics Limited report, Reference 313, March 1985.

Figure 2.3

The target strength of a uniform sphere whose circumference is much larger than the insonifying wavelength equals:

$$\text{Target Strength} = 20 \log \frac{a}{2} \quad \ldots\ldots \quad 2.1$$

where a is the radius of the sphere in metres.

For complex targets:

$$\text{Target Strength} = 10 \log \frac{\sigma}{4\pi} \quad \ldots\ldots \quad 2.2 \text{ (Urick, 1975)}$$

where σ (m^2) is the effective scattering cross section.

The target strength of a remote object can only be measured if the entire sonar system is calibrated. Appendix 2 describes the usual method of including the system parameters in the estimation of target strength. In most sonar work, it is assumed that the echo from the target occurs at a single point in space called the acoustic centre of the target.

With large targets, as in the case with icebergs, this is not the case. As discussed in Section 2.3, an iceberg could present many individual facets (targets) at various ranges. Because of the high range resolution of the transmitted pulse compared to the size of the iceberg, the echo appears as a cluster of smaller "resolved" echoes arriving over a period of time, causing power fluctuations in the received echo. One method to compensate for this effect is to integrate the power over the total duration of the echo and then compare the result with the energy of the transmitted waveform. This process was applied in the analysis of echoes from this trial and is hereafter referred to as "energy" or "total" target strength. In addition, a "peak" or "8 ms" target strength was defined and applied in the data analysis, as being the largest energy target strength for an 8 milisecond slice of the target echo. Comparison of the 8ms to the total target strength gives a convenient measure of echo "peakiness", a parameter which is important for detector design. Appendix 2 further reviews these two target strength definitions.

2.5 SCATTERING STRENGTH, SELF-NOISE AND TRANSMISSION LOSS

In addition to target strength, three other quantities that are acoustically relevant to ice hazard sonar detection, were estimated based on measurements made during the 1986 trial. These quantities are defined below. Their significance to the sonar detection process is discussed in more depth in Appendix 2, or in sonar textbooks (e.g. Urick 1975, Chapters 2, 3 5-8, 11 and 12).

The surface scattering strength S_s, measured in dB can be defined as the target strength of one square meter of (possibly, ice-covered) sea surface. This quantity is necessary for the calculation of the reverberation level. Scattering strength characterizes the ocean surface for a given geometry and operating frequency, and is otherwise independent of the sonar parameters.

Self noise (SN, dB Re 1μ Pa/$\sqrt{\text{Hz}}$) is the portion of the background noise received by a sonar transducer mounted on a ship, which is directly related to the ship and its movement. SN is measured in the receiving frequency band of the sonar considered, but is here expressed as a spectral density. Surface scattering strength and self noise measurements are important because they quantify the effect of the principal mechanisms producing the sonar background masking level, i.e. the "noise" background that can cause missed detections or false alarms. The two-way transmission loss (2 TL, dB) quantifies the attenuation suffered by sound during its propagation to and from the target, and, as such, is important in defining and predicting the performance of sonar systems.

2.6 OTHER EFFECTS

The sonar equation developed in Appendix 2 indicates that for a particular iceberg, the target strength should be independent of range. However at close range, only a small portion of the iceberg will be insonified. In addition, an ice/water interface is not a perfect reflecting surface. This suggests that differences will exist between a theoretical model and the actual situation. At larger ranges where more of the target is insonified, the target strength increases towards a limiting value. Conversely, at close ranges the target strength may be lower than theory predicts. Compensation for this loss in target strength can be applied to large icebergs when measured at short ranges.

2.7 STATISTICAL CONSIDERATIONS

From classical detection theory (e.g., DiFranco and Rubin, 1969), it is well known that the character of the fluctuations of radar and sonar targets is an important factor in the design and performance assessment of detectors for these targets.

In the particular case of the target strength which is of concern here, the following parameters have been used to characterize the fluctuations.

Mean:	The average value of the target strengths obtained for a given target (or a given run). This set of observations is referred to as the population.
Standard Deviation:	Most probable distance from the mean in the population considered.
Exponential Distribution:	A statistical distribution characterizing a large class of sonar targets made of unresolved scatterers. It is characterized by the fact that its standard deviation is equal to its mean.

Defining the precise significance of these concepts is outside the scope of this report. The interested reader is referred, for more details to any standard text on detection such as DiFranco and Rubin, 1969, or, at a more basic level, Urick, 1975.

3.0 PROJECT CONSTRAINTS, EQUIPMENT AND DATA COLLECTION

3.1 PROJECT CONSTRAINTS

The principal goal of the Phase II Close Range Acoustic Ice Hazard Detection Project was to collect and analyze data appropriate for assessing the merits and problems associated with sonar detection of ice locked bergs. The largest part of the data collection was accomplished using the C-Tech CDS-40A sonar system that had been installed on-board of the MV Arctic in 1984 for the first phase of the project.

It is useful to recollect (de Heering et al, 1985 Final Report, Chapter 3) that at that time the CDS-40A had been chosen as offering the most cost-effective and timely solution.

In particular, it was recognized then that the characteristics which qualify a sonar for iceberg detection are not necessarily those that make it ideal for calibrated acoustic measurements. For example, automatic gain control is unacceptable where amplitude measurements are concerned whereas, for detection, this technique is advisable. Also for the detection of small targets at long ranges, a narrow beamwidth is an advantage whereas in making observations of icebergs at close ranges, a wide beam is more appropriate.

Use of the C-Tech CDS-40A sonar led to the following sonar related constraints.

1. The CDS-40A operates at one frequency only, therefore, measurements over a range of frequencies is not possible.

2. The CDS-40A is not normally supplied for use in experimental procedures involving accurate amplitude observations. Thus, operator controls were not particularly suited for precise measurement.

3. The CDS-40A's transducer is deployed just below the hull of the ship, making it vulnerable to damage from ice pieces passing under the hull. (It is suspected that the transducer was damaged in this way on an earlier voyage.) This limited the data acquisition on ice-locked bergs to fixed geometries (ship stationary), and severely constrained the sonar self-noise measurements in ice breaking modes (see Section 4.5).

Several other constraints are inherent in the use of a large commercial vessel such as the MV Arctic for conducting sea trails. Manoeuvrability is an obvious restriction in sea ice and even in open water so that test runs which involved changes of geometry in ice took considerable time. Also as the ship was operating under a commercial charter, it was imperative that all trials be conducted within the allocated time period and close to the ship's commercial route.

3.2 EQUIPMENT

3.2.1 THE C-TECH CDS-40A SONAR

The CDS-40A sonar is normally supplied as a fish finding sonar system. The system comprises a transducer assembly mounted beneath the hull and a control and display unit mounted on the bridge. The CDS-40A sonar transducer transmits an omni-directional, 36 kHz cw pulse of known amplitude and duration. Its receiver has a vertical combined transmit/receive "audio" beamwidth of 12° and a horizontal "audio" beamwidth of 16°. These sonar characteristics as well as calibration information for the CDS-40A are described in C-Tech Report #898 . The sonar transmitter was mounted through a gate valve directly below the forward crane. The sonar bridge console is shown in Figure 3.1.

3.2.2. THE DATA ACQUISITION SYSTEM

The layout of the data acquisition system is shown in Figure 3.3. The received echo is amplitude modulated on a 1 kHz carrier and transmitted to the CDS-40A controller on the bridge via a co-axial cable. The signal is then demodulated and displayed on the television monitor in the standard PPI format. An operator-controlled cursor can be used to select the bearing of the target whose unprocessed echo can be monitored at the "audio" output connector. This "audio" signal is digitized by the Data 6000 Waveform Analyzer and also recorded by the B&K analog tape recorder for backup.

3.2.3 ANCILLARY EQUIPMENT

Additional equipment that was used during the trials includes the following:

(i) A Helle Model 1336, 36 kHz pinger. This pinger (see Figure 3.4) has a source level of 165 dB Re 1μPa at 1 m, is essentially non-directive and transmits one 10 ms pulse every second when put in contact with water. This unit was used for the propagation tests.

(ii) A Sea Bird salinity, temperature and depth profiler. The profiler (see Figure 3.6) was lowered in the sea, up to a maximum depth of some 120 m and environmental data was received and recorded by a dedicated microcomputer. The process proved to be very time consuming therefore only one profile per station was acquired.

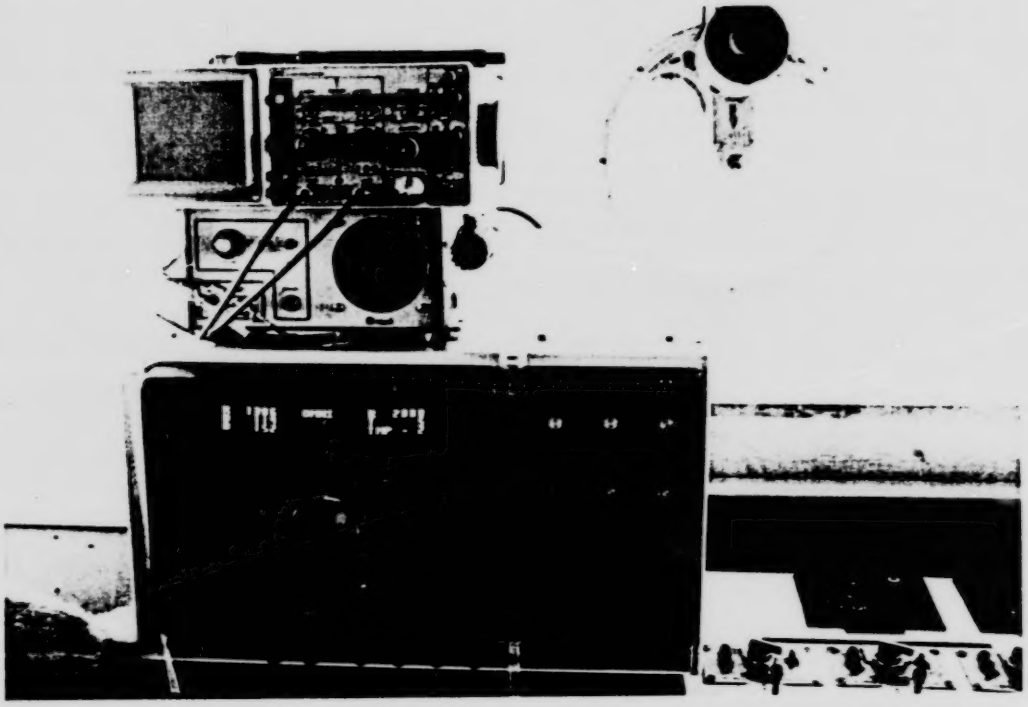


Figure 3.1 Control and Display Unit of C-Tech CDS-40A Sonar

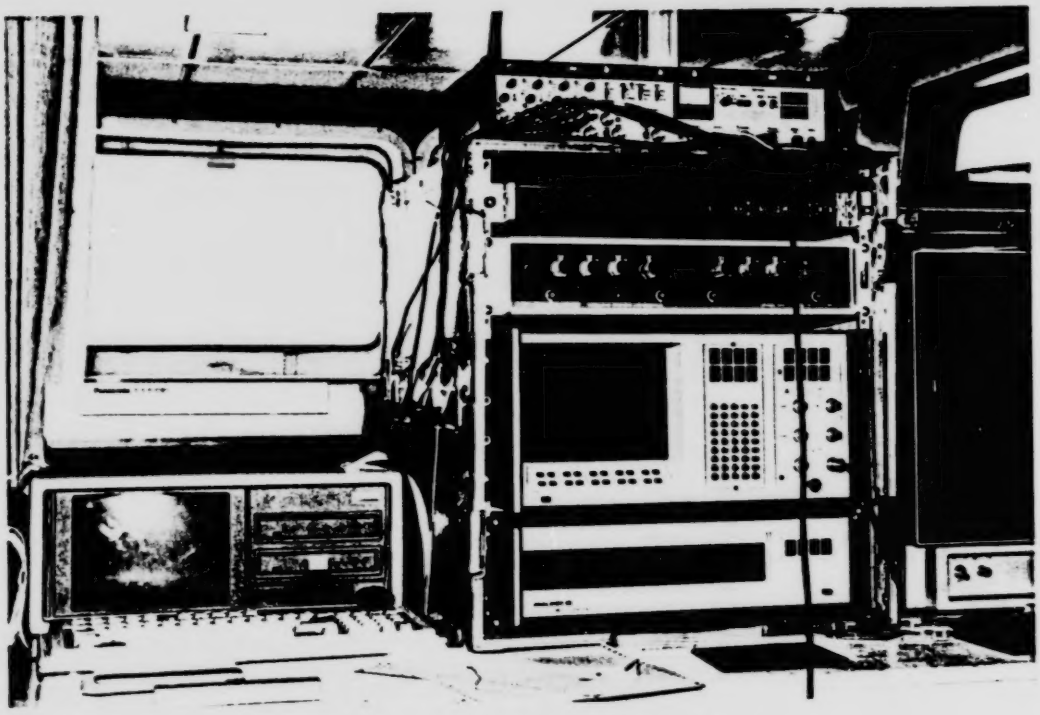


Figure 3.2 Data Acquisition System

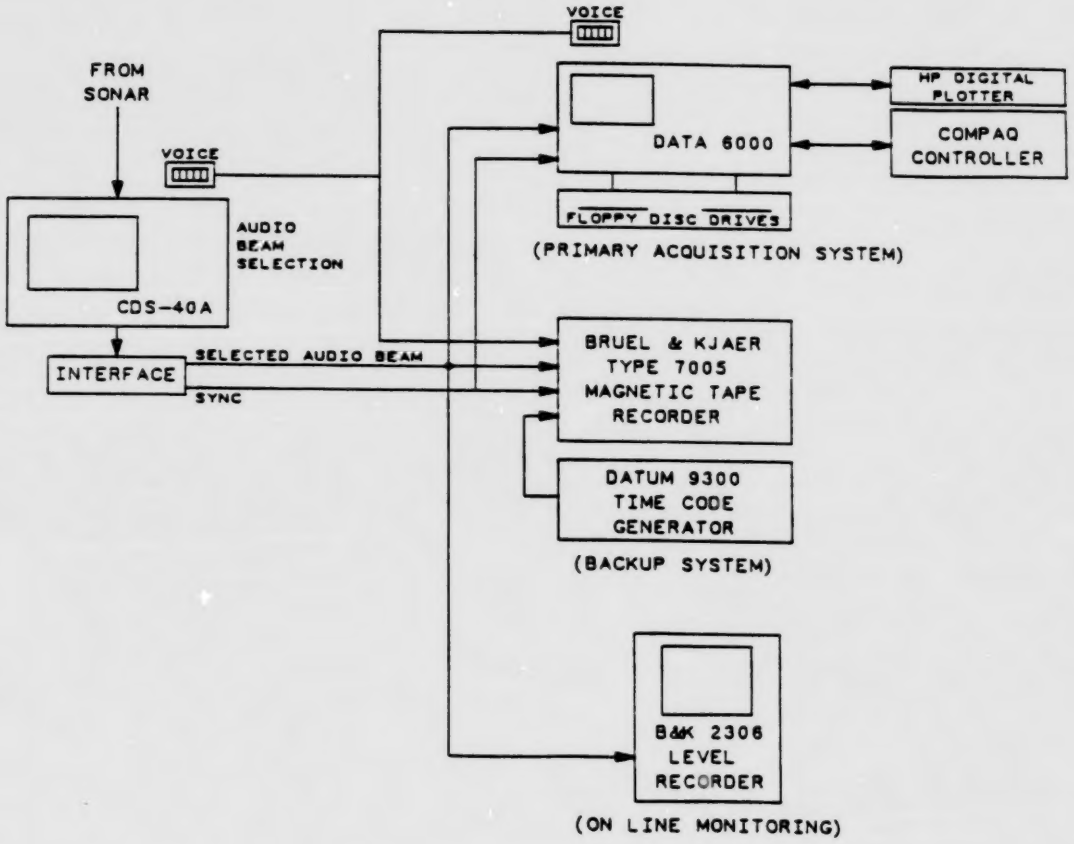


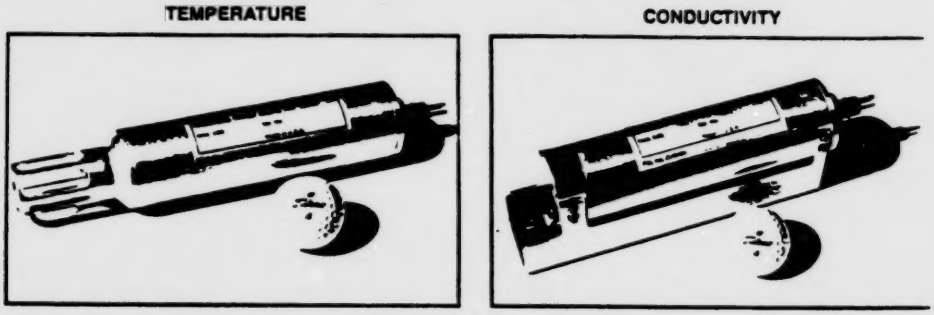
Figure 3.3 Data Acquisition Flowchart

Helle
ENGINEERING
Helle

MODEL 1327

Range: 2.0 mi (3.2 km)
Battery Life: 14 days
Depth: 10,000 ft (3,050 m)
Frequency: 27 kHz ± .1%
Power: 2 watts ± 3db
Ping Rate: 1 Pings/Sec. ± 20%
Pulse Length: 10 ms ± 20%
Voltage Range: 12-20 VDC
Normal Voltage: 18 VDC
Average Current: 2.9 mA
Activation Method: Immersion
Dimensions:
Length: 15.5 in (39.4 cm)
Diameter: 2⅝ in (6.6 cm)
Weight in Air: 5.5 lbs (2.5 kgs)
Weight in Sea Water: 2.3 lbs (1.1 kgs)
Shipping Weight: 7 lbs (3.2 kgs)

Figure 3.4 Helle Model 1336 36 kHz Pinger



SUBMERSIBLE
PUMP

Figure 3.5 STD Profiler

3.3 DATA ACQUISITION

The data acquisition procedure involves identification of the particular echo on the CDS-40A display and positioning the cursor as described above. The process of identifying the iceberg is critical to the whole procedure and is accomplished under manual control. The following list describes the use of the primary controls of the CDS-40A Display unit:

Power Level - The amplitude of the transmitted pulse is adjusted so that the return echo is visible on the CDS-40A monitor and the level recorded on the audio channel is less than 5 volts (peak to peak). This was the primary control used to insure that the target echo was at a level appropriate for calibrated acquisition.

Cursor - The cursor, a small white square visible on the PPI display is positioned by a joystick to the same bearing as the echo of interest.

STC Slope, Level and Gain - These three controls affect the sensitivity of the sonar receiver. Since the amplitude of the echo received from a target diminishes with range, compensation in the form of a time varying gain function can be applied. The net effect is to produce an echo whose intensity is nominally independent of range.

Dwell - Controls the repetition rate of the sonar pulses.

Tilt Angle - The "look direction" of the sonar transducer is electronically variable from 0 to -45° in the vertical plane. The tilt angle determines this direction. This control was normally set to -4°.

Width - Controls the duration of the pulse transmitted by the sonar. This control was normally set to the minimum pulse width available at each range.

All these parameters are set by controls on the front panel of the CDS-40A. This operation presented some difficulty during the actual data acquisition since changes in the relative position of the ship and target demanded that these controls be continuously adjusted. Although the potentiometers were graduated, it is possible that small setting errors were introduced. The potentiometer settings were logged during the data acquisition and ultimately used in the target strength calculations.

3.4 DATA RECORDING

The primary recording instrument for the echoes was the Data 6000 Waveform Analyzer. As a result of input rate limitations, the Data 6000 recorded one out of every four echoes. In order to avoid errors, automatic control of the recording process was provided by a COMPAQ Microcomputer. A two second data file with a sampling rate of 5 kHz was recorded by the Data 6000 Analyzer following a trigger pulse from the CDS-40A controller. For permanent storage, each data file was stored on floppy disc under a "filename" with the following format:

Dddhhmms.DAT

where dd = date
hh = hours (G.M.T.)
mm = minutes
s = decimal minutes

The CDS-40A controller settings and other relevant information were recorded in log books.

3.5 FIELD PROGRAM

The field trials involved manoeuvring the MV Arctic in close proximity to selected icebergs and recording sonar echoes continuously in open water and at selected ranges in sea ice. Five different types of manoeuvres were planned in order to collect sonar information over a comprehensive program of ranges, iceberg sizes and target directions. In addition, selected data on reverberation, propagation and self-noise were collected in the proximity of the iceberg targets.

The following definitions were used for the data acquisition periods or runs.

Run Type ALFA - Echoes from icebergs in ice or water.
Run Type BRAVO - Reverberation returns from total or partial ice cover.
Run type CHARLIE - Under-ice propagation.
Run type DELTA - Ship self-noise in ice-breaking mode or ice-free water.

Iceberg size was estimated by the ice observers and, in addition, the icebergs were documented by photographs taken at various aspects.

The actual trials took place in Lancaster Sound and Baffin Bay (see Figure 3.6) between July 6, 1986 and July 10, 1986 for a cummulative duration of 48 hours. A total number of 11 icebergs were measured involving several run types. A short diary of events is given in Appendix 3. The data collected during these trials was examined on board and a preliminary quality control analysis was performed. Sound speed profiles of the water column were obtained at regular intervals using the Sea Bird Electronics system in order to compute the underwater propagation characteristics. These are shown in Appendix 5.

On completion of the trails, the MV Arctic continued the voyage to Antwerp, Belgium arriving on July 20th, 1986. The scientific and technical personnel left the vessel at Antwerp and returned to Ottawa by air.

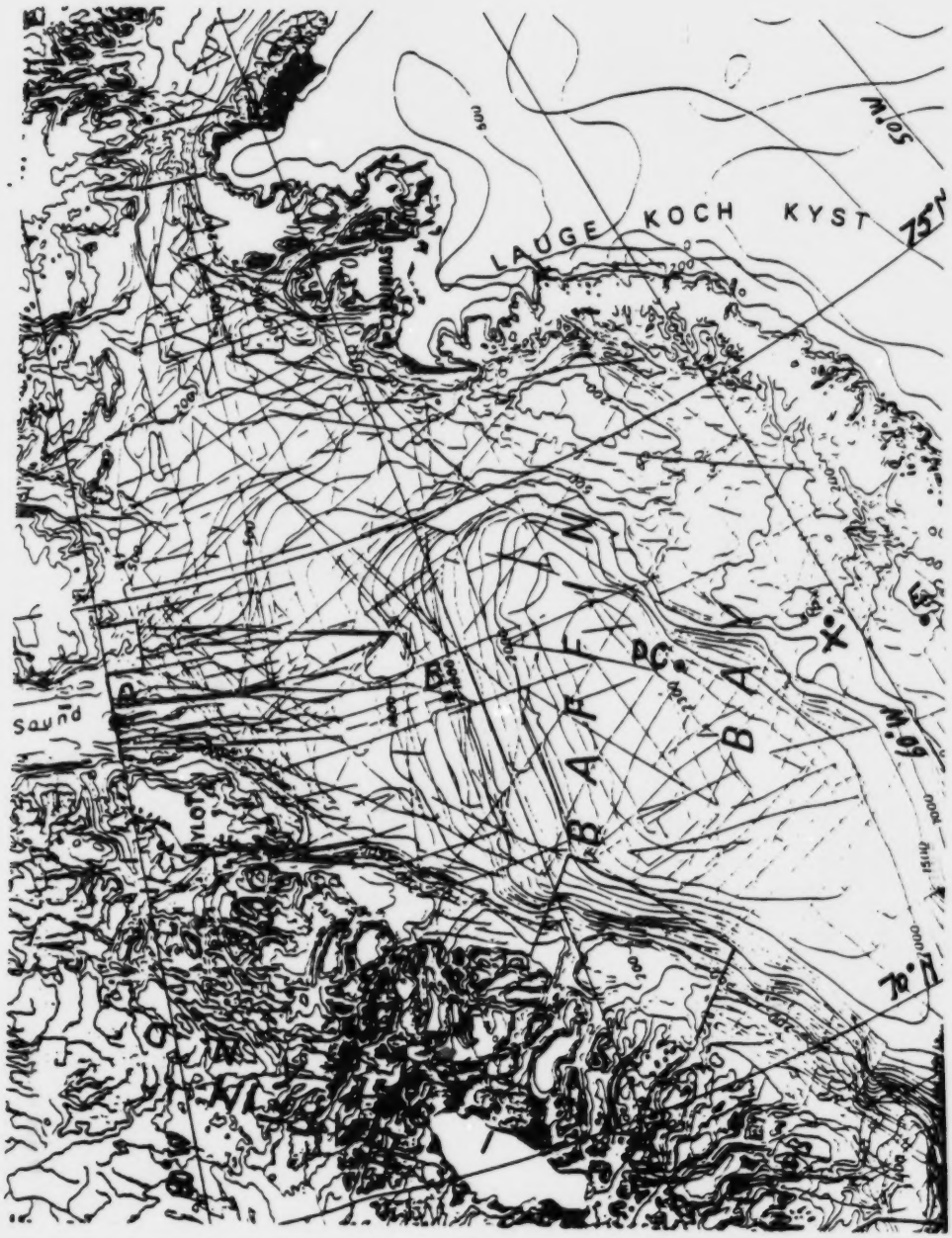


Figure 3.6 Location of Tests

A: July 6, 22:00 - July 7, 07:30 GMT;
B: July 7, 19:30 - July 8, 06:00;
DC: July 8, 17:30 - July 9, 08:30;
X: July 9, 15:00 - 24:00;
E: July 10, 06:00 - 13:30

4.0 PRESENTATION OF THE RESULTS, ANALYSIS AND DISCUSSION

4.1 SIGNIFICANCE OF THE RESULTS

The aim of this phase of the project is to present and interpret data showing whether the sonar detection of icebergs in the midst of sea ice is acoustically possible and, if so, under which conditions.

The first step of such an analysis often uses the sonar equation (see section 2.4, appendix 2 and Urick 1975), which is a convenient framework to organize the acoustic information of interest. The present work aims at elucidating those terms of the sonar equation that depend on the target and environment, with emphasis on ice - covered waters. Analysis and design work relating sonar system parameters to the sonar equation is outside the scope of the present work as are mechanical and other system considerations.

This chapter summarizes the results of this Phase II of the project under the categories Target Strength, Reverberation, Propagation and Sonar Self-noise and Maximum Detection Range together with an indication of the data reduction processing applied.

4.2 ICEBERG ECHOES

4.2.1 PROCESSING OUTLINE

A total of some 950 sonar returns were digitally recorded from 11 different icebergs of which 5 were in ice covers ranging from 5/10 to 10/10 and 6 were in open water. Of these, 829 were used for target strengtn calculation. The relatively small number of ice-locked targets results from poor visibility, which made the location of targets difficult, the time used for repositioning the ship in ice and the fact that the ship had to follow a specific commercial route. However, it is felt that the ice-locked targets that were studied, together with the understanding acquired with the open water targets are adequate to provide a good phenomenological representation of the properties of the echoes of ice-locked bergs. The

processing of the recorded the echo data is flowcharted in Figure 4.1. While most of the signal processing was carried out on a Data 6000 digital processor, subsequent graphical and statistical processing was done on PC-based Lotus software.

For the purpose of target strength processing, the twoway transmission loss (see Section 2.5 and Appendices 2 and 5) was taken as being caused by spherical spreading plus absorption (10dB/km), at the exclusion of other focussing effects due to the sound speed profile. It is shown in Appendix 5, that for the propagation conditions encountered during the field work, this assumption would cause only small errors (of the order of a few decibels at most) which are almost negligible with respect to those caused by the temporal and spatial variability of the sound speed profile. The only exceptions concern the targets encountered in open water. Anomalously low target strength values obtained at ranges close to the maximum detection range, where only a small portion of the target is insonified, were not included in the statistical data base.

4.2.2 TARGET STRENGTH ESTIMATES

Target strength was measured at the sonar frequency of 36 kHz. The total and peak (8 ms) target strength values resulting from the processing of the echoes were each pooled for each of the eleven targets encountered and the mean and standard deviation of the observed sample of target strength values was calculated for each case.

The mean target strength results are given in Figures 4.2 and 4.3 for total and peak target strengths respectively. In these figures, the ice-locked and open water targets are identified.

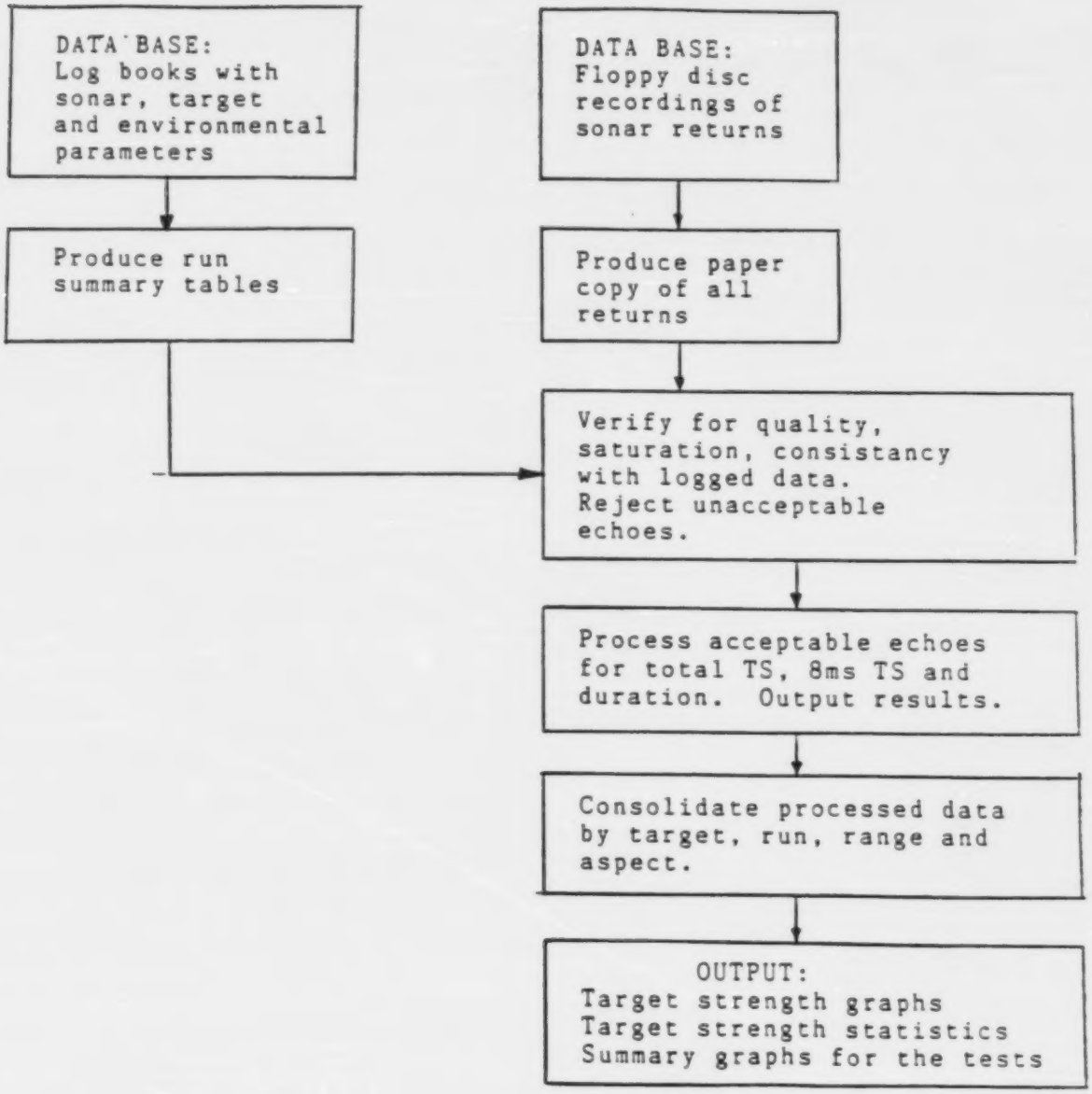

DATA BASE:
Log books with sonar, target and environmental parameters
DATA BASE:
Floppy disc recordings of sonar returns
Produce run summary tables
Produce paper copy of all returns
Verify for quality, saturation, consistancy with logged data. Reject unacceptable echoes.
Process acceptable echoes for total TS, 8ms TS and duration. Output results.
Consolidate processed data by target, run, range and aspect.
OUTPUT:
Target strength graphs
Target strength statistics
Summary graphs for the tests

Figure 4.1 Flowchart of Processing for Target Strength Estimation

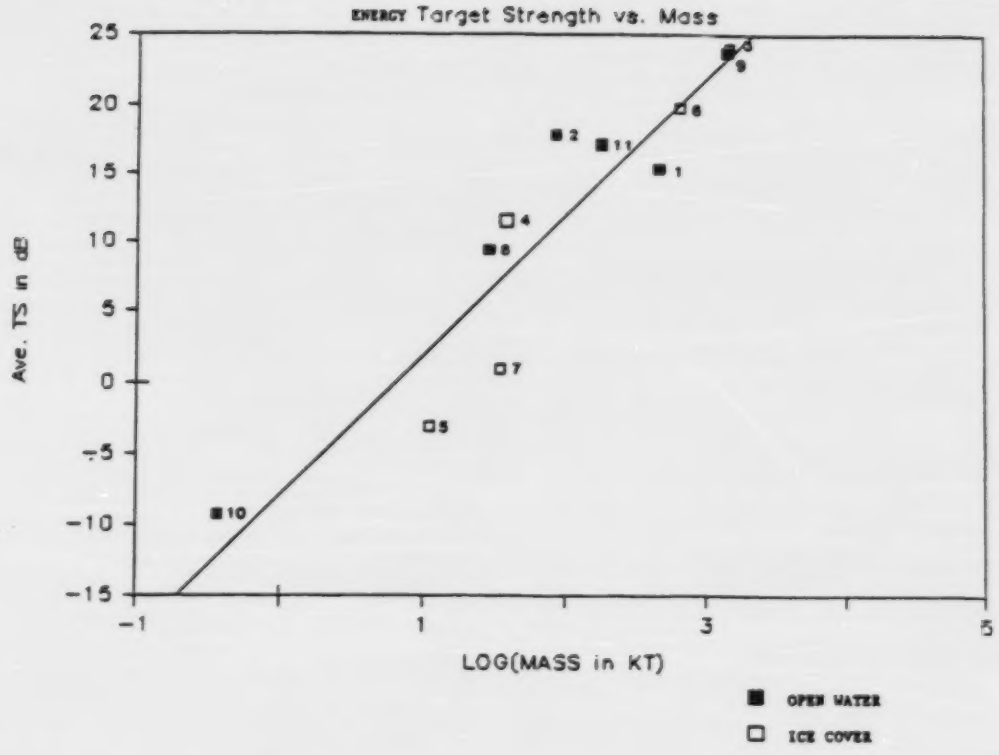


Figure 4.2

Total target strength, 1986 data, (36 kHz)

Numbers refer to target numbers (see Appendix 4). Black and white squares correspond to open water and ice-locked icebergs, respectively. The slant line represents the total target strength of a smooth spherical ice target of the mass indicated without internal reflection.

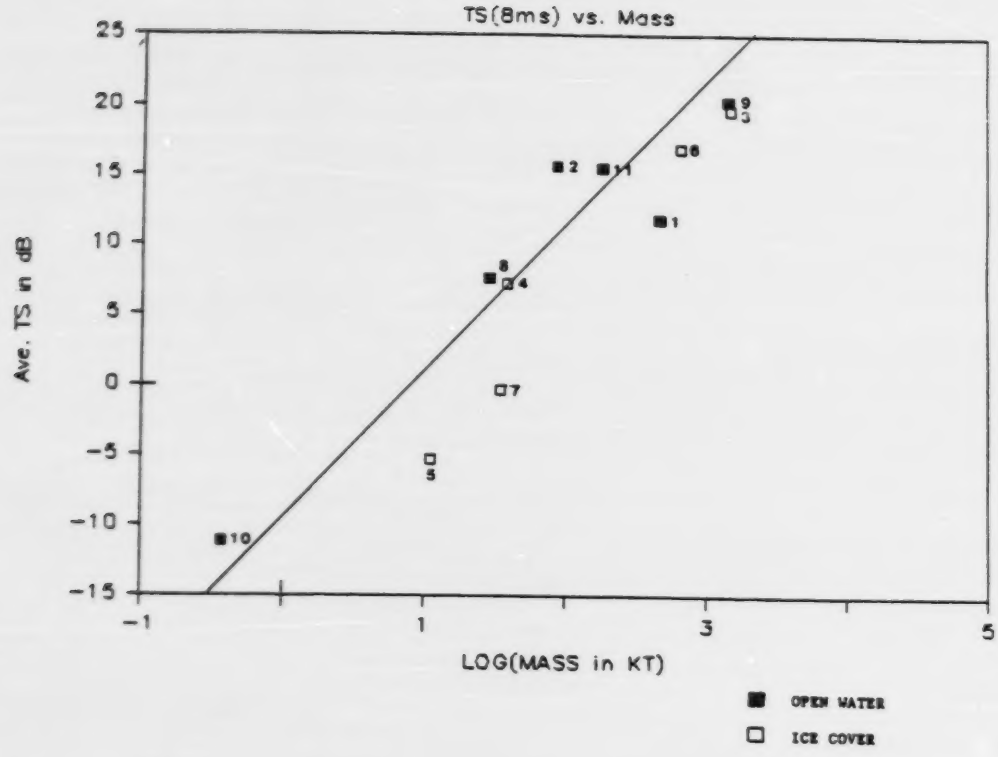


Figure 4.3

Peak target strength, 1986 data. (36 kHz)

Numbers refer to target numbers (see Appendix 4). Black and white squares correspond to open water and ice-locked icebergs, respectively. The slant line represents the total target strength of a smooth spherical ice target of the mass indicated without internal reflection.

A line representing the target strength of a smooth ice sphere with no internal reflections, which was proposed (de Heering et. al, 1985, Final Report) as a phenomenological model for iceberg average target strength is represented on the figures.

This model can be expressed by:

$$TS = 6.7 \log M - 18dB \qquad (4.1)$$

where TS is the iceberg average sonar target strength (dB)
M is the iceberg mass in metric tonnes.

Figure 4.4 combines mean total target strength estimates from the Phase I work, with those given in Figure 4.2

Values for the standard deviation of the target strength observations, as well as observation histograms are given in Appendix 4 for each individual target.

The following conclusions can be derived on the basis of the data summarized in Figures 4.2 - 4.4 and in Appendix 4.

(i) **The target strength model expressed by Equation 4.1 appears to be supported for both open water and ice-locked icebergs.**

(ii) **The total target strength values are, on average, some 3 dB higher than the peak (8ms) target strength values.** This implies that, on average, about half of the energy of iceberg echoes is contained in one 8ms time interval i.e. 6m range extension.

(iii) **The target strength data obtained in 1986 is consistent with that of 1984,** although the latter appears to be somewhat lower on average. Reasons for the difference may include inaccuracies in data acquisition (saturation) or processing (inaccurate compensation for propagation) that may have affected 1984 data, as well as differences in target and environmental conditions.

(iv) **The observed standard deviation for each target is generally of the order of the mean target strength.** This behaviour was also noted with the 1984 results, and is typical of an echo made out of a large number of uncorrelated scatterers. (DiFranco & Rubin, 1969)

4.2.3 ECHO DURATION

The echo duration was estimated at the same time as the target strength. The echo duration is here defined as being the duration corresponding to the central 80% of the total echo energy. The observed mean echo durations are given in Figure 4.5 as a function of the estimated mass of the iceberg. Median echo durations observed during the 1984 data acquisition phase are also represented and shown to be similar to the present data. Echo durations corresponding to range extents of one-quarter, one-half and three-quarters of the radius of an ice sphere of a mass equal to that of the iceberg are also marked on the figure.

The following conclusions can be derived from the data summarized in Figure 4.5:

The average echo duration produced by the observed icebergs is bracketted by that produced by an object extending in range between one-quarter and three-quarters of the radius of a ice sphere of mass equivalent to that of the berg. That is:

$$\frac{R}{4} \times 2/c \leq \text{Echo Duration, Average} \leq \frac{3R}{4} \times \frac{2}{c}$$

where (R is the radius of an ice sphere of mass equal to that of the berg and c is the speed of sound in water.)

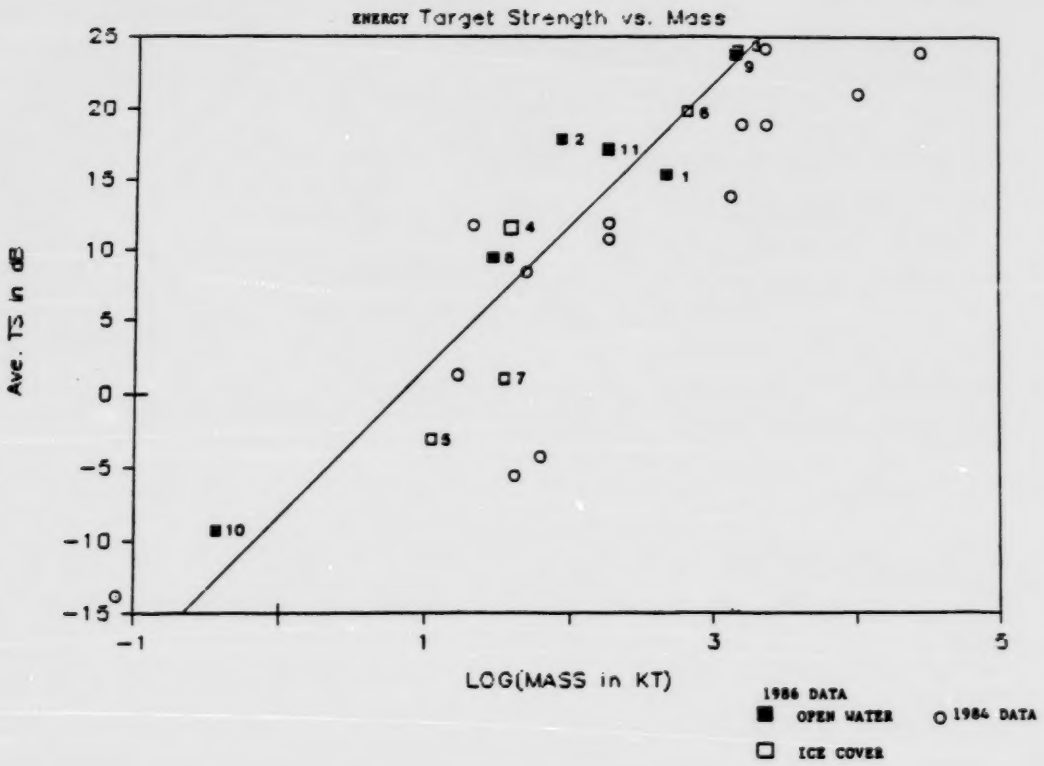
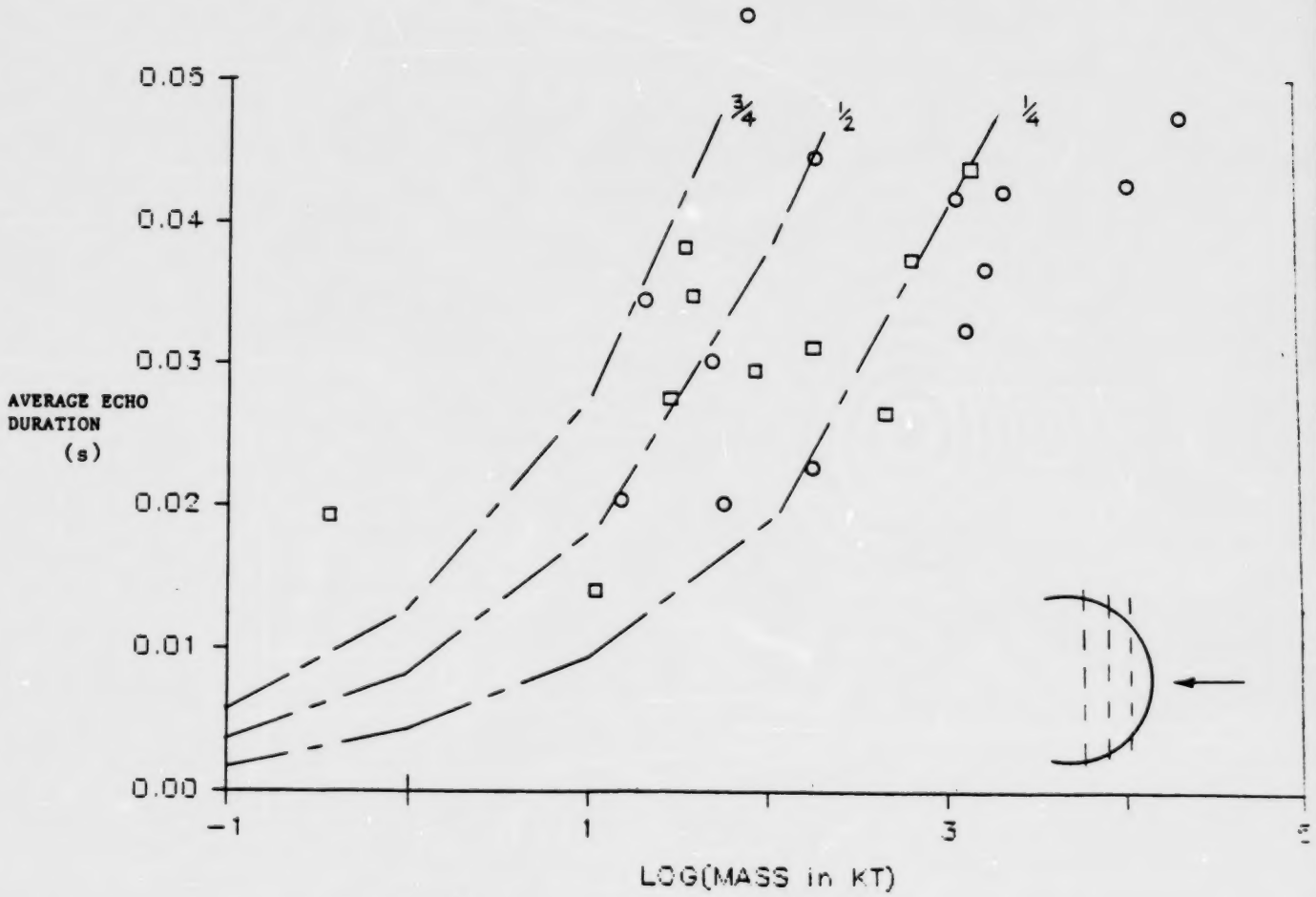


Figure 4.4 Pooled 1984 (circles) and 1986 (squares) Total Target Strength Data (36 kHz)



- Anomolous effects due to poor signal-to-reverberation ratio.
—·— Echo duration from range extension = R of sphere of equal mass.

Figure 4.5 Echo Duration as a Function of Estimated Mass

"Squares" mean echo duration, 1986 data; "Circles" median echo duration, 1984 data. Durations corresponding to range extents of 1/4, 1/2 and 3/4 of the radius of ice sphere of mass equivalent to that of the berg.

4.2.4 CONCLUSION

The echo properties observed are consistent with the observations made during Phase I of this work. Average target results observed at 36 kHz are similar to those that would be produced by smooth ice spheres of mass equivalent to that of the target berg. Average echo duration is of the order of that corresponding to a range extent of one-quarter to three-quarters of the diameter of the said ice sphere. Approximately one-half of the echo energy is contained in an eight millisecond slice of the echo.

4.3 REVERBERATION

4.3.1 PROCESSING OUTLINE

As discussed in section 2.5 and Appendix 2 the reverberation process is best characterized by the scattering strength S_s, which in principle depends on the frequency, the environment and the geometry only, while the effect of the other sonar system characteristics has been taken out.

Figure 4.6 is a flowchart of the processing leading to the estimation of the apparent surface scattering strength. 'Apparent' is used here to indicate that the processing is done as if (as is generally the case in ice-covered waters - see Mellen 1963,1965 and 1985, Chapman 1966 and Birch 1971) the reverberation were caused by the surface ice (as will be seen, this is probably not the case).

4.3.2 REVERBERATION

Data from two reverberation runs (No. 33 and 47) is summarized in Figure 4.7. Details on the environmental conditions prevailing at the time of the data acquisition are given in the appropriate sections of Appendix 4.

As indicated in Figure 4.6, sample points corresponding to range brackets that are contaminated by discrete targets (icebergs) are eliminated from the output. Such is the case in Run No. 33 data, for the samples belonging to the 200 - 400 m range bracket. For Run No. 47, scattering strength samples beyond 400 m in range are contaminated by the bottom echo, as the water depth is 400 m for that run.

4.3.3 DISCUSSION

Comparison of the apparent Surface Scattering Strength observed in these two runs (viz -45 to -55 dB in Run No. 33 and -65 to -75 dB in Run No. 47) to the few values available in the literature around 36 kHz (see Mellen, 1965, 1985, Chapman,1986) shows that the present figures are of the

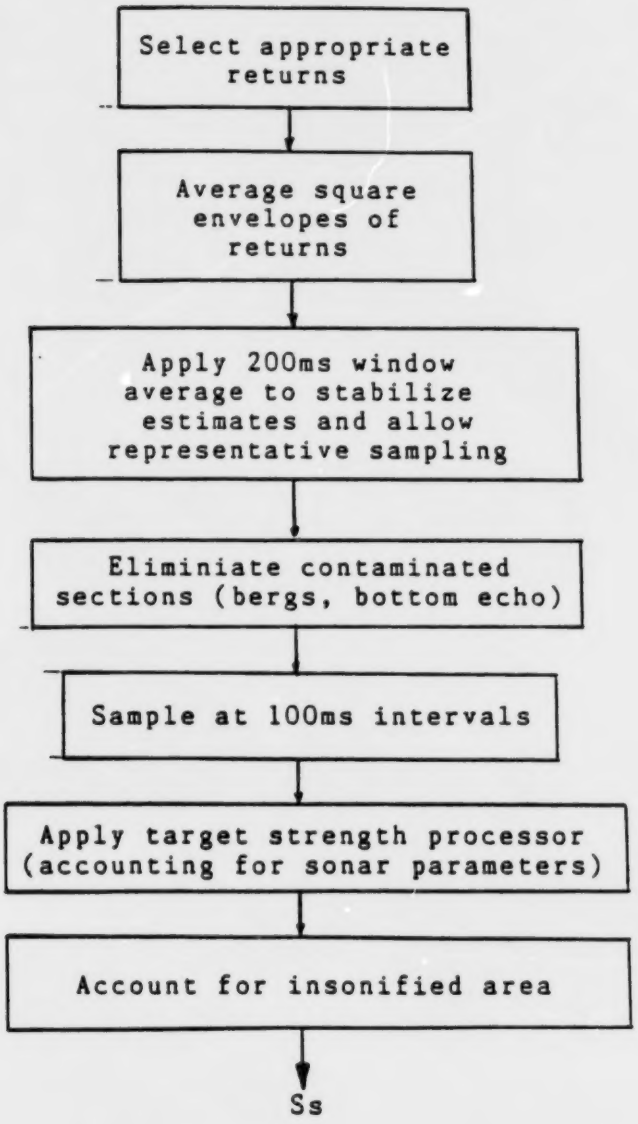

Select appropriate returns
Average square envelopes of returns
Apply 200ms window average to stabilize estimates and allow representative sampling
Eliminiate contaminated sections (bergs, bottom echo)
Sample at 100ms intervals
Apply target strength processor (accounting for sonar parameters)
Account for insonified area
Ss

Figure 4.6 Flow Chart of Processing for Estimating the Apparent Surface Scattering Strength S_s

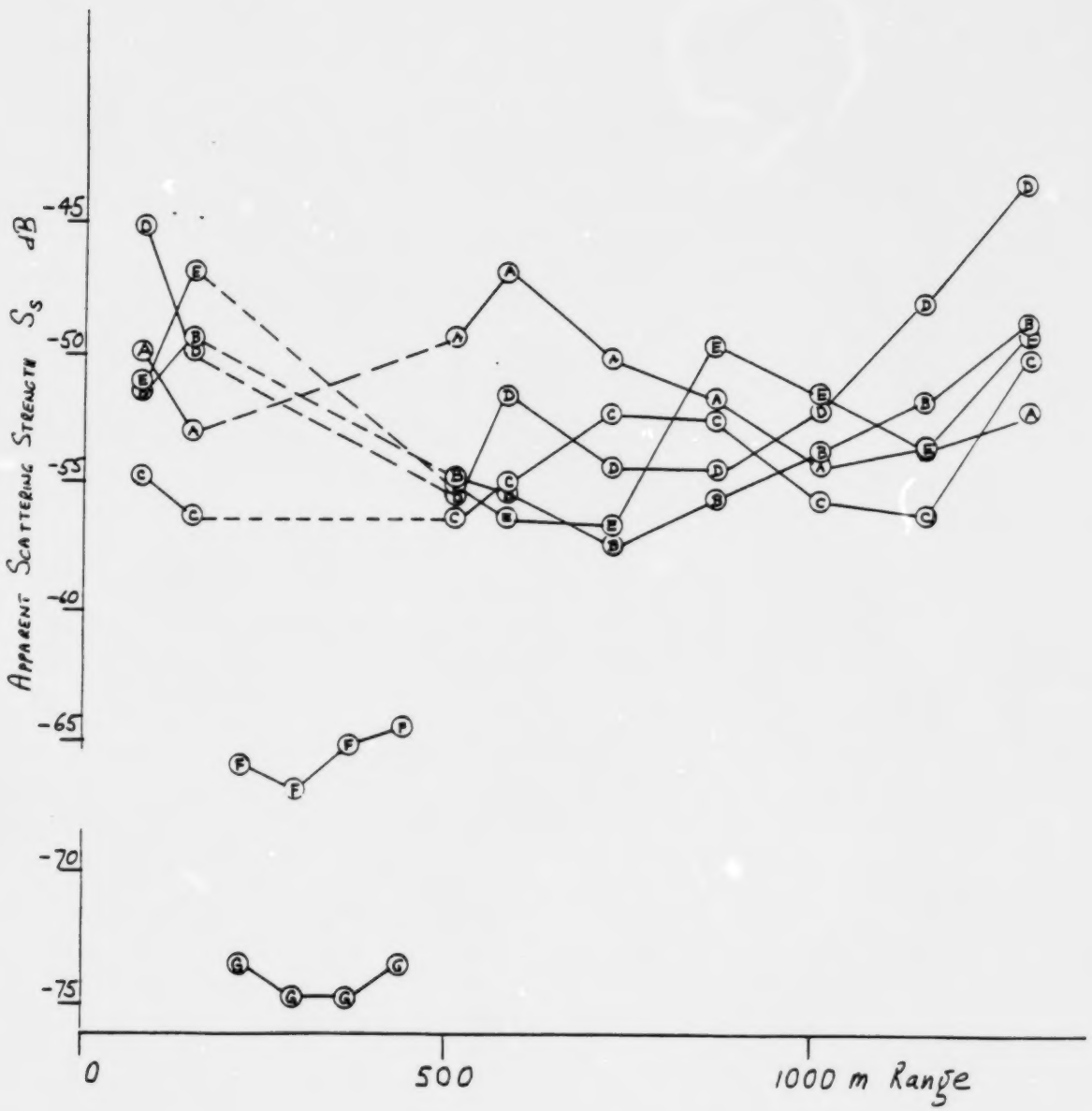


Figure 4.7 Apparent Ice Cover Surface Scattering Strength Measured During Reverberation Runs.

A -D Run #33 7 July 1986, 22:00 GMT
F, G Run #47 9 July 1986, 19:00 GMT

A	0° look Direction	D	180°	G	89°
B	90°	E	270°		
C	135°	F	218°		

same order as the Marsh and Mellen model (e.g., p.6 Figure 4 of Mellen 1985) which indicate frequency independent S_s between -50 and -70 dB for small grazing angles. However, observed values for the Arctic quoted in the same source or in Urick 1975 Figure 8.34 would result in S_s of the order of -20 to -30 dB. Somewhat lower values were measured in the Canadian east coast waters (-30 to -45dB) as reported by Chapman et. al, 1966.

This significant difference in scattering strength could have resulted from the fact that most of the cited values were obtained in long range, low frequency conditions, contrary to the present. However, this is not likely, as observed surface strength values tend to increase with increasing frequency.

The more probable interpretation is derived from the examination of the ray-trace diagrams: Figure 4.8 for Run No. 33 (BAFFINB) and Figure 4.9 for Run No. 47 (BAFFINX). (These diagrams are also presented with other pertinent information in Appendix 5.) The diagrams represent acoustic "rays" originating at the source (sonar) on the left-hand of the figure as they are refracted by the sound speed gradient existing in the water column, and reflected by the boundaries. More detailed treatment can be found in Urick 1975, p. 114. For present purposes it should be noted that the ray angles at the source have been chosen according to the effective vertical beam width of the sonar. In fact, the shading effect of the ship's hull limits the sonar beam to some 0.5 to 1 degree above horizontal. For the measured sound speed profiles, this results (see enlargement of BAFFINB profile, Figure 4.10) in the ice-covered sea surface being in the shadow of the hull. This effect is believed to be present in most propagation conditions characteristic of ice-covered sea.

It is therefore logical to attribute the low scattering strength levels reported in Figured 4.7 to volume reverberation rather than reverberation from the ice.

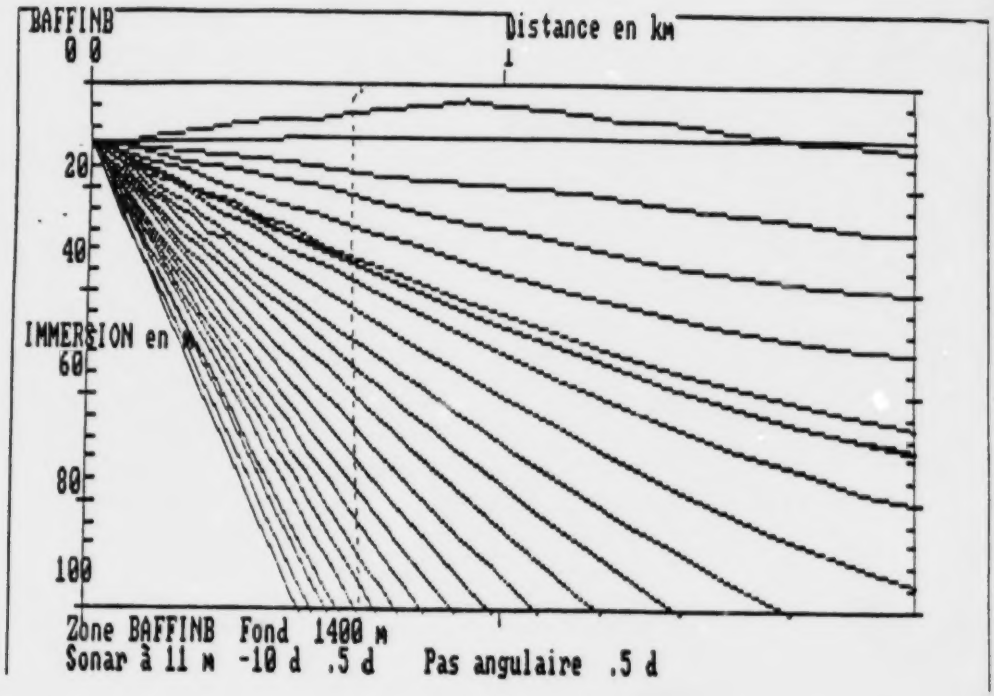


Figure 4.8 Ray-trace Diagram for Run No. 33

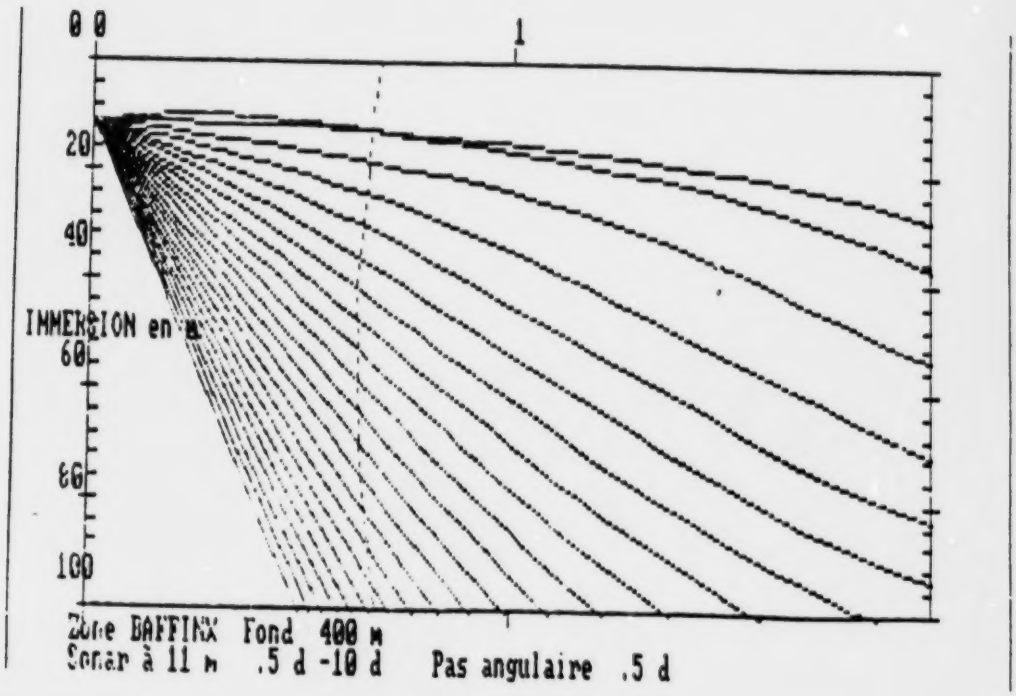


Figure 4.9 Ray-trace Diagram for Run No.47

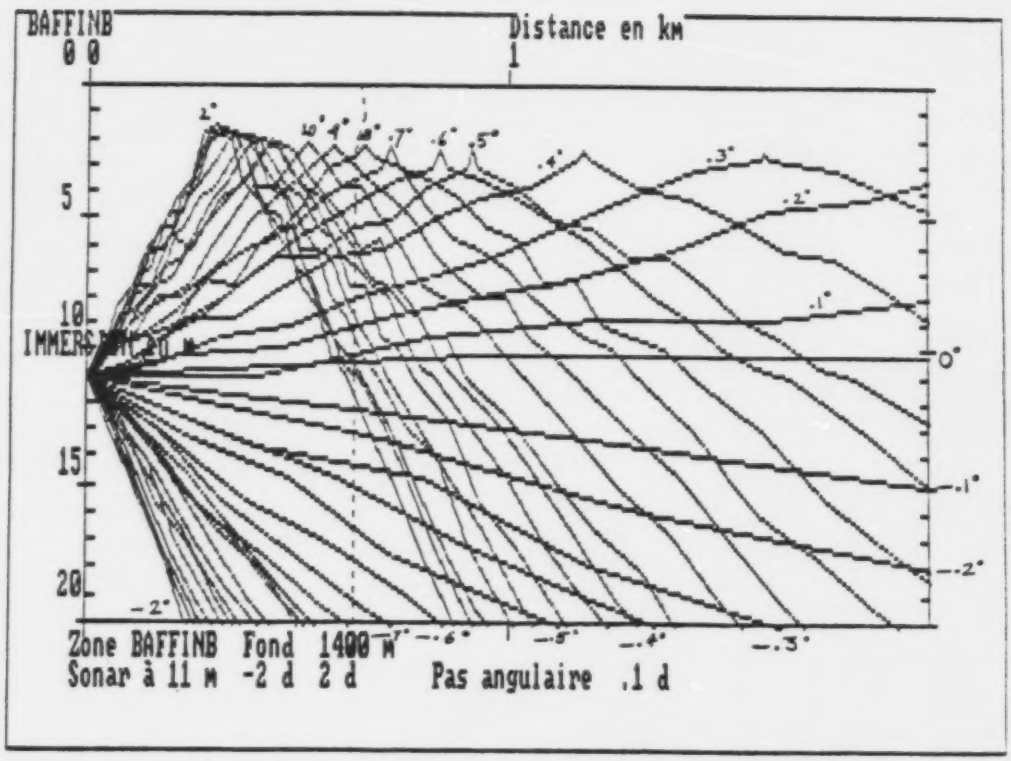


Figure 4.10 Enlargement of Ray-trace Diagram for BAFFINB

This interpretation is confirmed by the general observation made during the tests that the reverberation levels observed were much lower than expected from the literature.

The discussion above can be summarized thus:

(i) Very low reverberation levels were encountered under the ice (-45 to -65 dB/m² of surface), which are likely due to volume reverberation.

(ii) The M.V. Arctic hull appears to cast an acoustic shadow over the ice canopy, which is effective in strongly reducing the observed reverberation. This effect is believed to be quite general in ice-covered waters.

(iii) This acoustic shadow may result in reduced detectability of very close and very shallow ice obstacles, but it strongly contributes to the general detectability of icebergs in reverberation-limited conditions.

4.4 PROPAGATION

4.4.1 MODELLING AND MEASUREMENT

The significance of the propagation loss in the process of sonar detection of underwater targets is explained in Section 2.5, as well as in Appendices 2 and 5. Propagation is one of the factors determining the echo level, and as such, is particularly important in the noise-limited detection process.

For the purpose of the Phase II work described in this report acoustic propagation was both modelled and measured. These two aspects are examined below.

4.4.2 PROPAGATION MODELLING

Sonar propagation can be predicted by means of a variety of propagation models, of varying complexity. A good overview of the simpler ones is given in Urick 1975, Chapters 5 and 6. For the purpose of the present work, two models have been used.

(i) Spherical Spreading Plus Absorption

This is the simplest model. It assumes that the acoustic pressure decreases as a function of range by the effect of spherical spreading of the acoustic power, plus a frequency dependent absorption term. In the more customary decibel (or logarithmic) notation this is expressed as:

$$TL = 20 \log R + \alpha R \qquad (4.1)$$

where TL is the one-way transmission loss (dB)
R is the range
α is the absorption coefficient (dB/m). At 36 kHz and 0°, $\alpha = 0.01$ dB/m.

This equation was used in the calculation of target strength values.

(ii) Ray Tracing

At the higher acoustic frequencies, the propagation of acoustic power in the water can be modelled as occurring along acoustic rays, the curvature of which is proportional to the vertical sound speed gradient in the water. Hence, measurement of the vertical sound speed profile allows one to generate propagation predictions. This is done in Appendix 5 of this report.

Two examples are discussed below (full profile information is presented in Appendix 5).

BAFFINA profile during the first test period (July 6, 23:10 to July 7, 07:00 in open water (see Figure 4.11)). This is typical of open water propagation conditions in the summer. Warmer shallow layers of the sea result in rays bending downward, which results in an effective "shadow zone" when acoustic detection is next to impossible. In Figure 4.11, this zone extends from the surface to some 1 m at the source, down to some 60 m at 1 km range.

BAFFINB, obtained during the second test period (July 7, 20:00 to July 8, 06:00) is typical of under-ice propagation conditions (see Figure 4.12). The sound speed profile is such that good insonification is obtained at all depths.

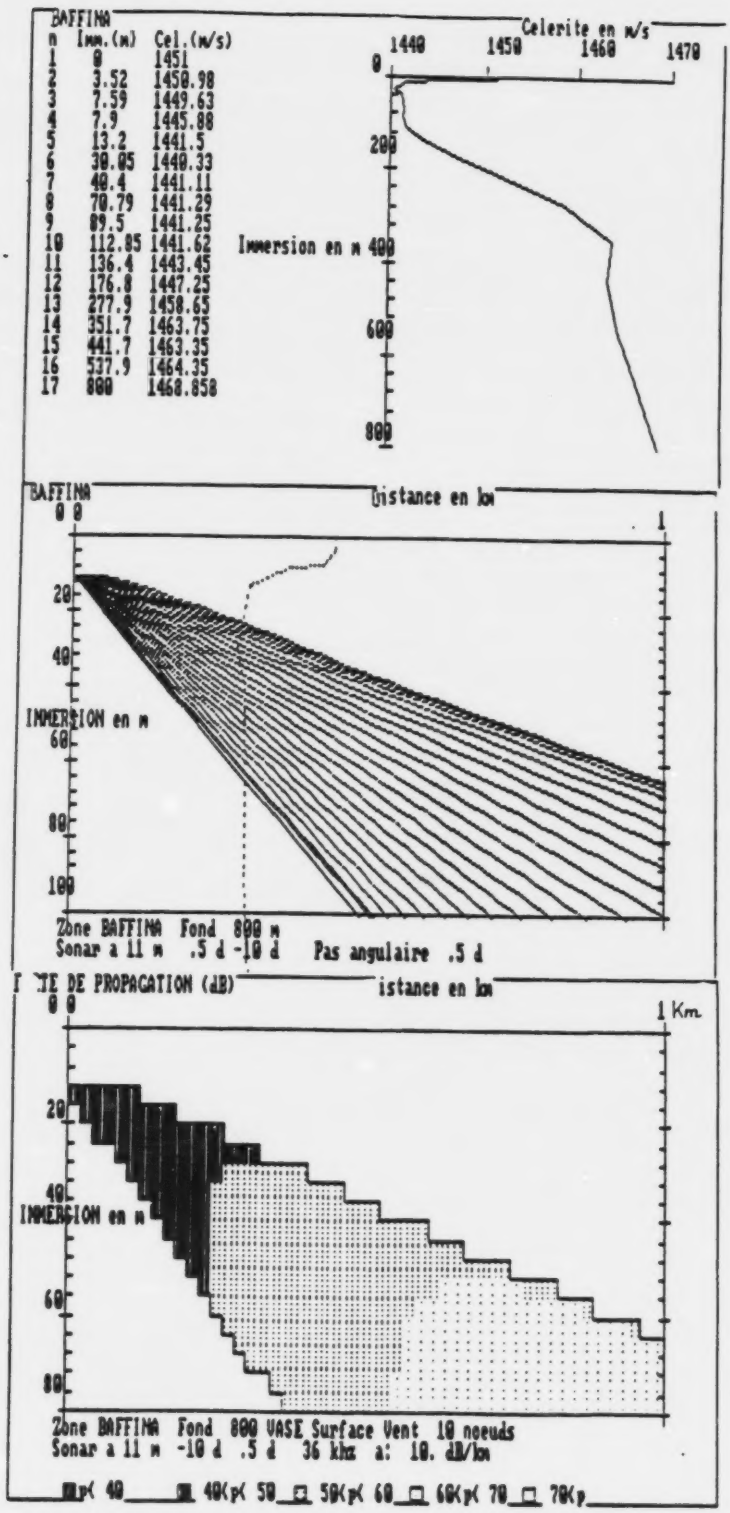


Figure 4.11 Sound Speed Profile, Ray Trace and Insonification Prediction with Downward Refracting Profile, BAFFINA

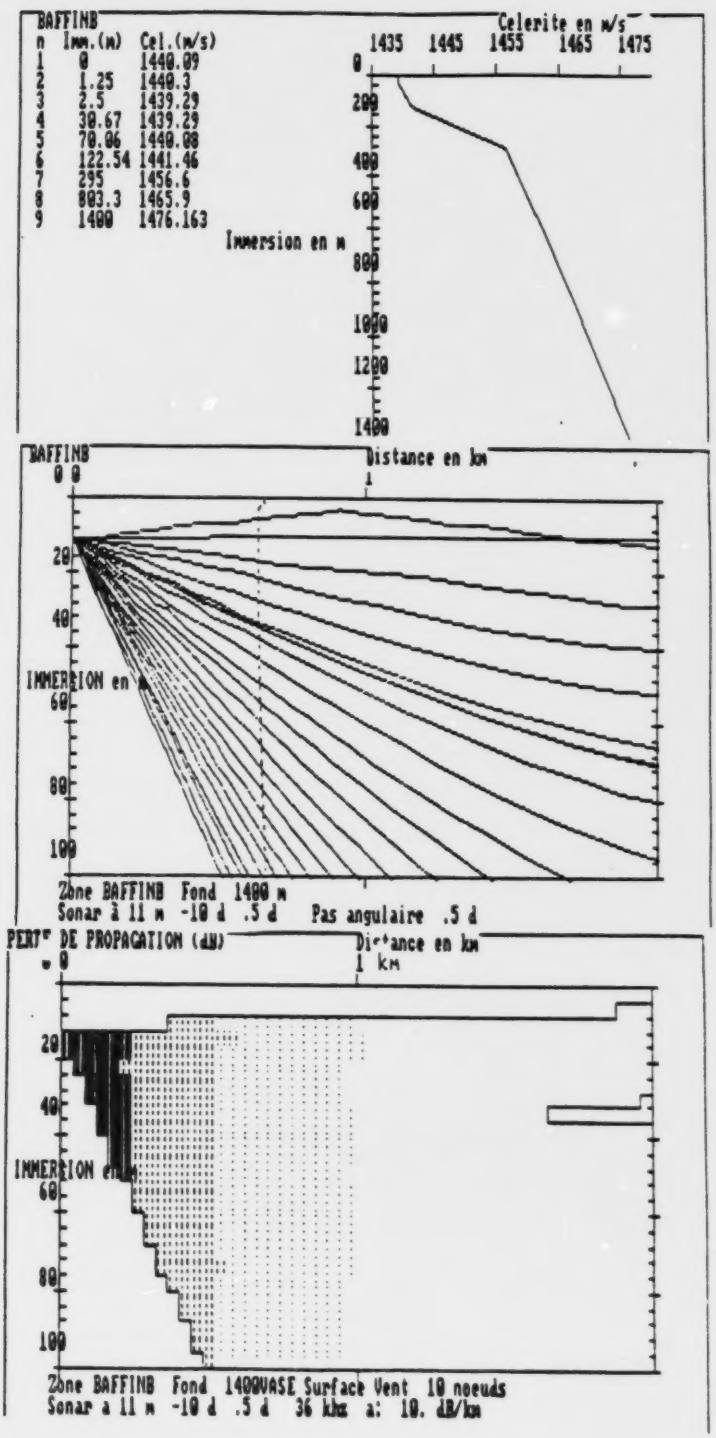


Figure 4.12 Sound Speed Profile, Ray Trace and Insonification Prediction with Slightly Upwards Refracting Sound Velocity Profile: BAFFINB

Programs such as Iceberg (Baldour, 1984) are used to predict the propagation loss. The agreement with observed effects is generally good providing sound speed profile information is adequate. A serious problem can arise due to the time, and space variability of the sound speed profile, which was difficult to ascertain for this project because of the relatively brief time period.

4.4.3 PROPAGATION MEASUREMENTS

Propagation measurements were carried out on three occasions, in the test zones BAFFINB, BAFFINDC and BAFFINX (see map in Appendix 5). The propagation measurements were carried out by receiving the impulses produced by a 36 kHz pinger (see Section 3) deployed at a known depth, with the CDS 40A sonar which was set in the receive-only mode.

On the first occasion, where the 36 kHz was deployed at the ship's stern, inadequate documentation on the sonar setting rendered the data questionable.

On the second occasion, in the BAFFINDC test area, the 36 kHz source was deployed at various depths (up to 40 m) at 400 and 200 m ranges in holes through the ice, but no signals were received. Note in Appendix 5, the large difference between sound propagation prediction resulting from the two sound speed profiles recorded on that day.

In the BAFFINX zone, the 36 kHz source was deployed both from the ship's stern and through the ice (see Appendix 4, runs No. 35-36). The transmission loss results are summarized in Table 4.1 below.

Table 4.1 Measured Transmission Loss in Runs No. 35-36
July 9, 16:15 - 17:57 GMT

Under-ice propagation from 36 kHz pinger to sonar.
Pinger source level = 165 dB Re 1μPa @ 1m.

Run #	Tilt °	Received Level dB Re 1μPa	Source depth m	Estimated Range m	Deployed from
35	5	115	30	212	Stern
36	5	98	15	212	Stern
37	5	85	30	170	Ice surface
38	5	89	45.5	170	Ice surface
39	5	70	15	170	Ice surface
40	5	70	10	170	Ice surface
41	5	66	5	170	Ice surface
42	5	66	30	380	Ice surface
43	11	70	30	380	Ice surface
44	5	70	45.5	380	Ice surface
45	5	60	15	380	Ice surface
46	5	62	5	380	Ice surface

The results shown in Table 4.1 indicate a propagation loss that is generally larger than what would be predicted on the basis of the sound speed profile. (see Appendix 5 - BAFFINX)

Run No. 35 is one exception where the 115 dB received level is very close to what is predicted by equation 4.1. Reasons for this discrepancy are not entirely clear. They may include:

(i) The shadowing by the ship's hull, which would significantly affect transmissions from a depth shallower than some 20 or 15 m.

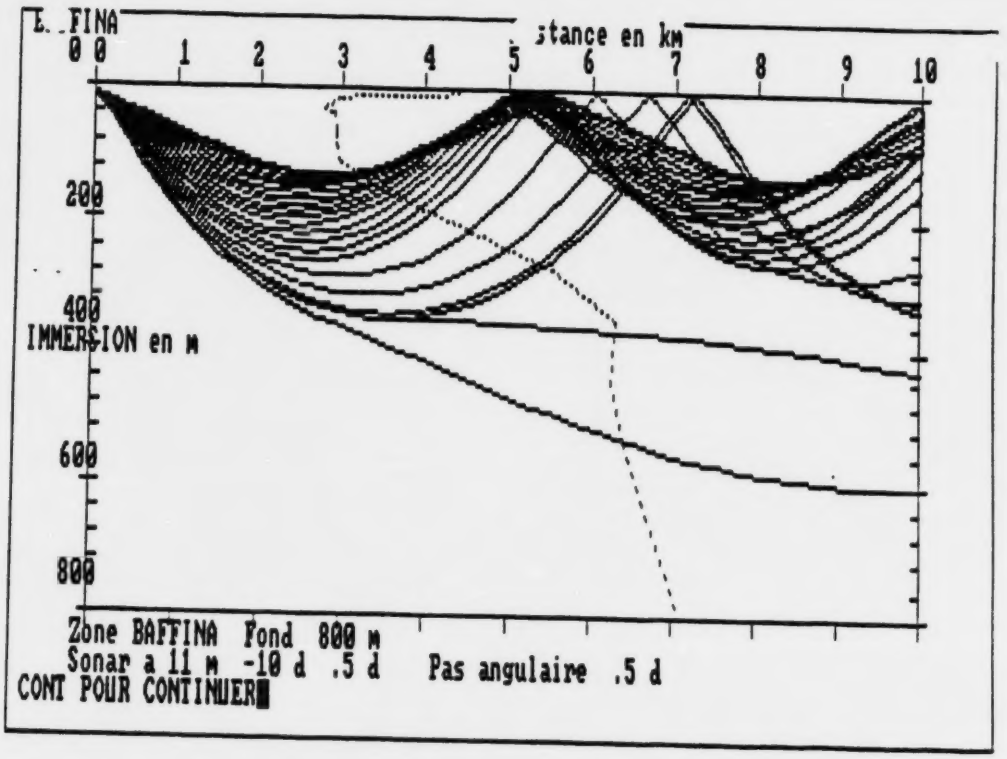
(ii) Inaccurate estimates of the range. Range estimates were done by the ice observers, mostly by eye.

(iii) Variability of the propagation. The sound speed profile was measured some one hour later than the propagation measurements. Note that Appendix 5 shows that this profile generates large range fluctuations in propagation.

(iv) Anomalous operation of the sonar. However, the sonar control settings were well controlled.

4.4.3 TARGET DETECTION BEYOND THE FIRST SHADOW ZONE

Propagation loss predictions such as those presented in Figure 4.11 ("downwards bending") indicate detection ranges that would be limited by the downward refracting sound speed profile. However, closer investigation of the propagation revealed that under propagation conditions typical of the Arctic, the acoustic rays converge in a layer close to the sea surface at some 5 km from the sonar. This is illustrated in Figure 4.12 for the BAFFINA sound velocity profile, which is representative of open water conditions in that season. This convergence area (the "first convergence zone") is used by naval sonars for detection of submarines. In the North Altantic conditions, the first convergence zone is normally at a distance of some 40 - 60 km from the sonar. In the Arctic, it is seen that the low surface temperature results in the first convergence zone to be much nearer.


stance en km
0 0 1 2 3 4 5 6 7 8 9 10
200
400
IMMERSION en M
600
800
Zone BAFFINA Fond 800 M
Sonar a 11 M -10 d .5 d Pas angulaire .5 d
CONT POUR CONTINUER

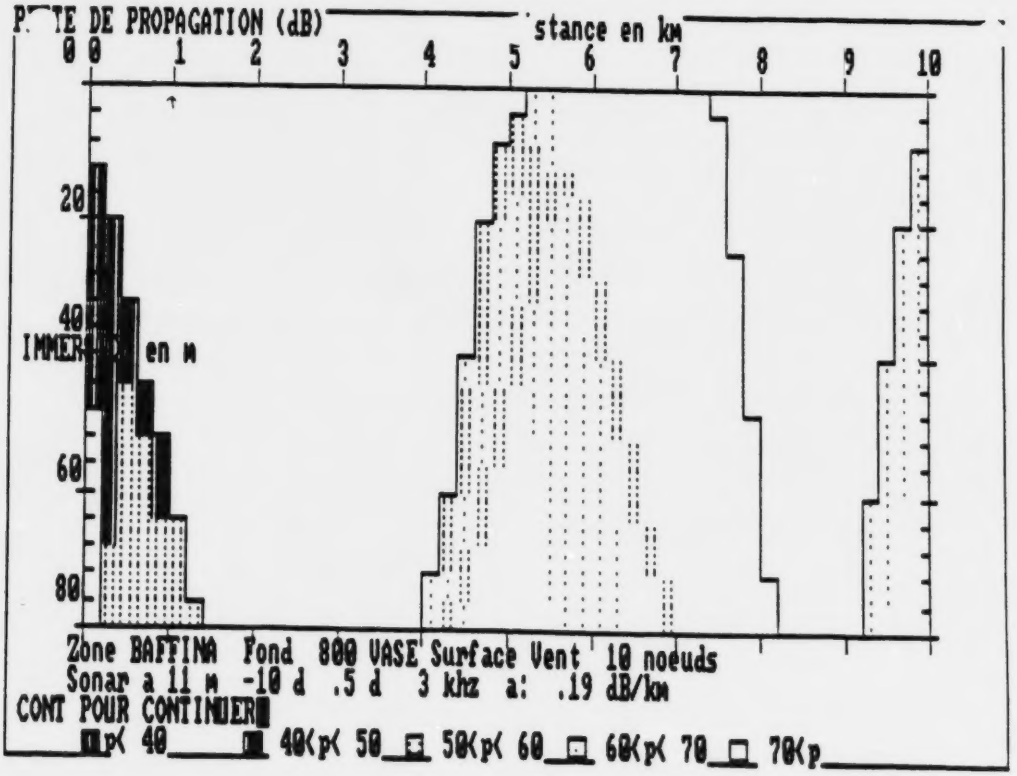

stance en km
0 0 1 2 3 4 5 6 7 8 9 10
20
40
en M
60
80
Zone BAFFINA Fond 800 VASE Surface Vent 10 noeuds
Sonar a 11 M -10 d .5 d 3 khz a: .19 dB/km
CONT POUR CONTINUER
p< 40 40<p< 50 50<p< 60 60<p< 70 70<p

Figure 4.12A Propagation into the First Convergence Zone

This suggests the interesting possibility of sonar being able to operate in open water in an ice hazard detection role at intermediate ranges. Lower operating frequencies however, would be needed to overcome the effects of a proportionally higher absorption loss.

4.5 DETECTION RANGES

4.5.1 INTRODUCTION

Maximum detection ranges constitute a parameter of primary interest for the purpose of defining the iceberg detection performance of a sonar. It was seen in Section 4.4 that, in downward refracting conditions, close range detection is limited by the shadow zone formed between the sea surface and the refracted beam of the transducer. As an example, in the ray tracing graphs corresponding to the BAFFINE situation (see Figure 4.13) it can be observed that the ray emanating from the source at a +0.5° elevation angle defines the limit of the shadow zone at a depth of 11 m at range 0 and some 50 m at range 1 km from the source.

The differences between profiles such as BAFFINE which correspond to ice-free summer conditions and those prevailing in ice-covered waters (such as in BAFFINB) were discussed above. Most significantly, it was seen that the type of propagation prevailing in ice-covered waters is likely to produce longer detection ranges. This section attempts to quantify and model these effects with more precision.

4.5.2 MODEL AND MEASUREMENTS

For the purpose of modelling the maximum propagation-limited sonar detection range, it was assumed that backscattering of the sonar transmission is done primarily by the top half of the submerged iceberg. This is not unreasonable in view of the general underwater shape of many bergs (see Petrocan Exploration 1983) which are characterized by steep sides and a rounded bottom. Further it was assumed that detection is possible only at ranges where the top half of the iceberg is insonified.

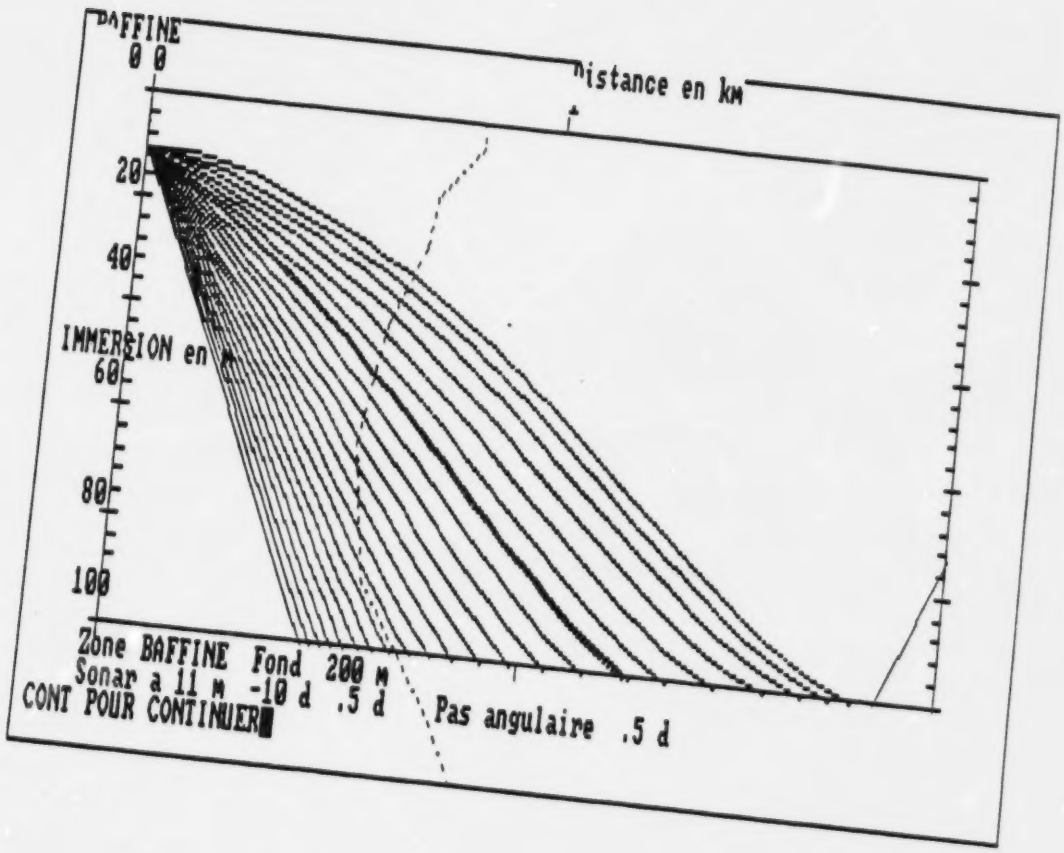


Figure 4.13 BAFFINE Ray Tracing Diagram

The maximum detection ranges resulting from this assumption are represented in Figures 4.14 and 4.15, as a function of range (the propagation conditions shown in BAFFINE, taken as typical). The experimental maximum detection ranges were plotted on the same graphs, as explained below.

In Figure 4.14, the maximum detection ranges were plotted as a function of the iceberg estimated* draft.

It can be seen that, notwithstanding the simplicity of the model, the observed open water maximum detection ranges line up fairly well with the predicted line. Most ice-covered water ranges are significantly longer.

In Figure 4.15, the maximum observed detection ranges for each berg was plotted as a function of the radius of an ice sphere of mass equivalent to the estimated iceberg mass. This model yields a fair prediction of the maximum detection range of open water icebergs. Again, the ice-locked bergs exhibit detection ranges that are significantly larger, as they are not limited by downwards refraction effects in the acoustic propagation.

* according to ice observers on-board M.V. Arctic and Canadian Coast Guard guidelines given in Chapter 1 of this report.

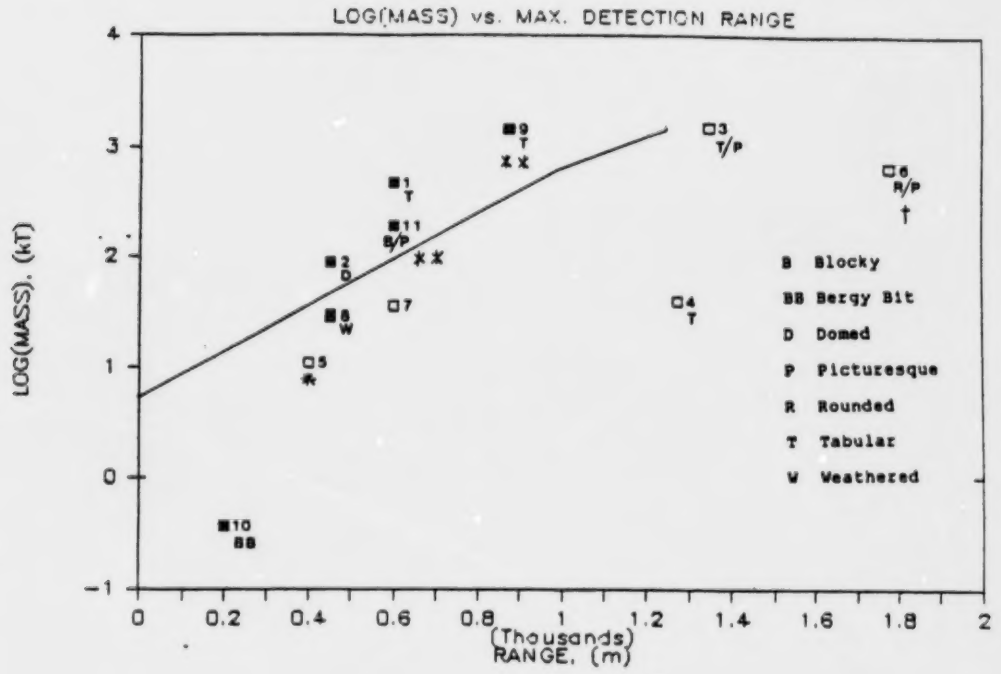


Figure 4.14 Maximum Detection Range as a Function of Estimated Mass

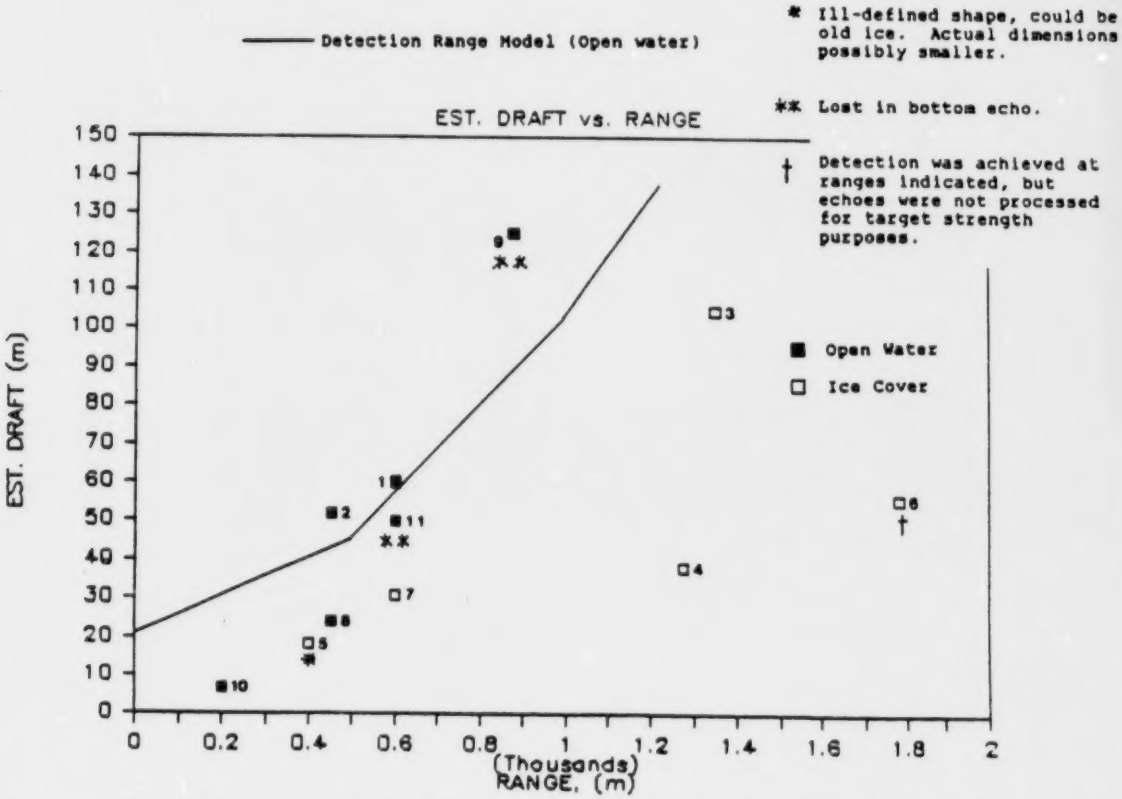

Detection Range Model (Open water)
* Ill-defined shape, could be old ice. Actual dimensions possibly smaller.
** Lost in bottom echo.
† Detection was achieved at ranges indicated, but echoes were not processed for target strength purposes.
EST. DRAFT vs. RANGE
EST. DRAFT (m)
(Thousands)
RANGE, (m)
Open Water
Ice Cover

Figure 4.15 Maximum Detection Range as a Function of Estimated Draft

4.6.3 CONCLUSION

Data analysis supports the observation that, in conditions of a downward refracting sound speed profile (i.e. Arctic summer open water propagation), the maximum detection range is approximately equal to the range at which the shadow zone reaches one-half of the iceberg draft. In conditions of upward refracting sound speed profile (characteristic of ice-covered waters) maximum detection range appears to be limited by reverberation or noise, depending on the acoustic parameters.

4.6 OPEN WATER AND ICEBREAKING SELF-NOISE MEASUREMENTS

4.6.1 INTRODUCTION

The self-noise of a vessel is defined (Urick 1975, Chapter 11) as the noise received by the measurement transducer which originates from the vessel itself or from its interaction with water. Self-noise is the dominant component of the sonar background when the ship is breaking ice. Its measurement is therefore of key importance to predict the noise background to which an ice detection sonar will be subjected when operating from an ice-breaking ship. In this case, the noise background is the most likely factor limiting the performance of an iceberg detecting sonar.

The measurement of self-noise from the M.V. Arctic while breaking ice was recognized in the Test Plan (de Heering, April 1985) to be risky for the transducer as it is not ice-reinforced and could be damaged by a piece of ice. The ice breaking self-noise measurements were therefore conducted towards the end of the trial. Also, some of the measurements were conducted with the transducer in a position just inside the hull, in order to obtain a preliminary indication of the noise levels encountered. Finally the measurements in ice were kept very brief, a few minutes in total. As a result, the transducer remained intact, while useful data was obtained.

Open water self-noise measurements were also conducted, as detailed below.

4.6.2 MEASUREMENTS

The CDS 40-A was set up for noise measurements by reducing the transmitted power to zero. This mode of operation reduced the sonar to a passive, listen only, mode. The noise data received was recorded on a Bru l and Kjaer type 2306 level recorder and later converted into received acoustic sound levels according to the sonar calibration data.

The measurements were carried out within the sonar effective input bandwidth of 2 kHz at 36 kHz centre frequency. The data presented below is reduced to a bandwidth of 1 Hz.

All the measurements were carried out with the ship at icebreaking draught.

Figure 4.16 summarizes the results of measurements conducted in open water with the transducer assembly fully extended. The levels observed are constant with the ones observed in 1984 and generally below 26 dB Re 1μPa.

Part of the icebreaking self-noise measurements were carried out with the sonar transducer raised to be just inside the ship's hull. These measurements were carried out to ascertain the transducer sensitivity in that position. This was done by comparing the noise received with a fully extended vs. half-extended transducer, in otherwise similar conditions. By necessity, this comparison was carried out in open water. Figure 4.17 summarizes the data obtained. It is apparent that the half-extended reception mode corresponds to a received level attenuated by some 6 to 8 dB with respect to the fully extended mode. This result should, however, be used with caution, as the mechanism of noise generation and transmission to the transducer is probably very different in open water, with respect to ice-covered water.

Figure 4.18 summarizes the measurements of self-noise with the M.V. Arctic in ice breaking mode. The speeds used range from 0 to 3 knots, the two ice conditions encountered were 8/10 broken ice and 10/10, 120 cm thick first year ice. While the figure shows significant variability, general observations can also be made:

(i) Self-noise levels measured in broken ice conditions are relatively low (20 dB Re 1μPa @ 2 knots). This is not likely to effect sonar reception in a significant way.

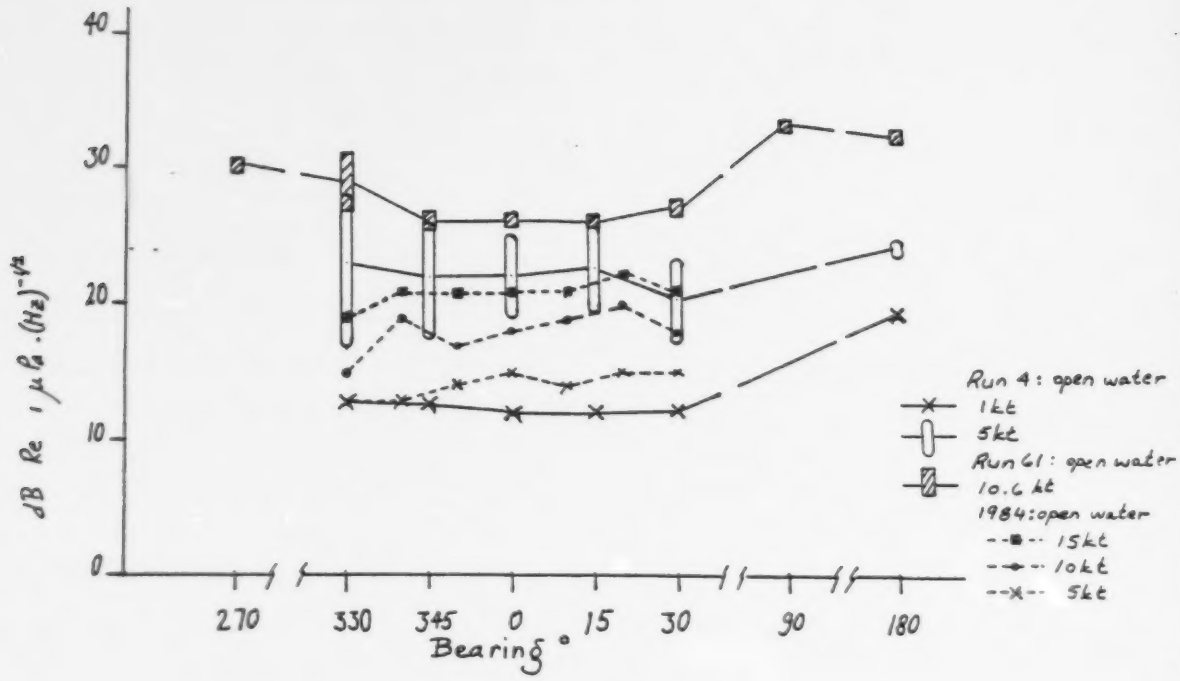


Figure 4.16 Open Water Self-noise Measurements with Fully Extended Transducer Assembly

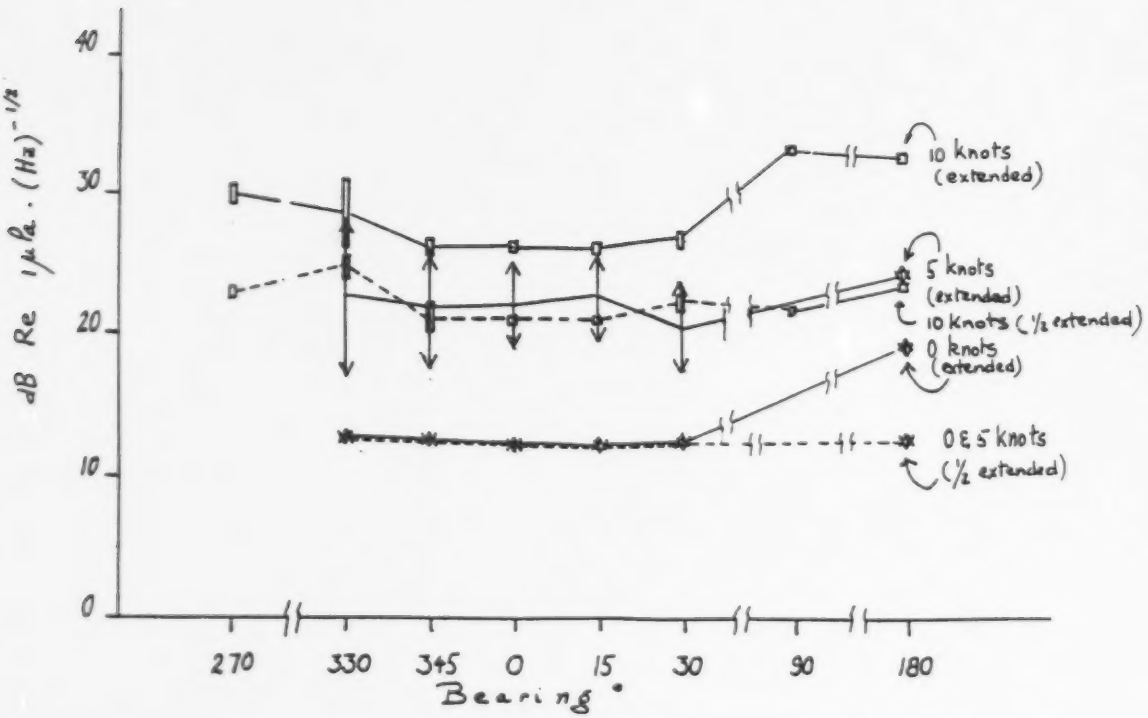


Figure 4.17 Comparison of Received Levels of Extended vs Half Extended Transducer Assembly in Open Water

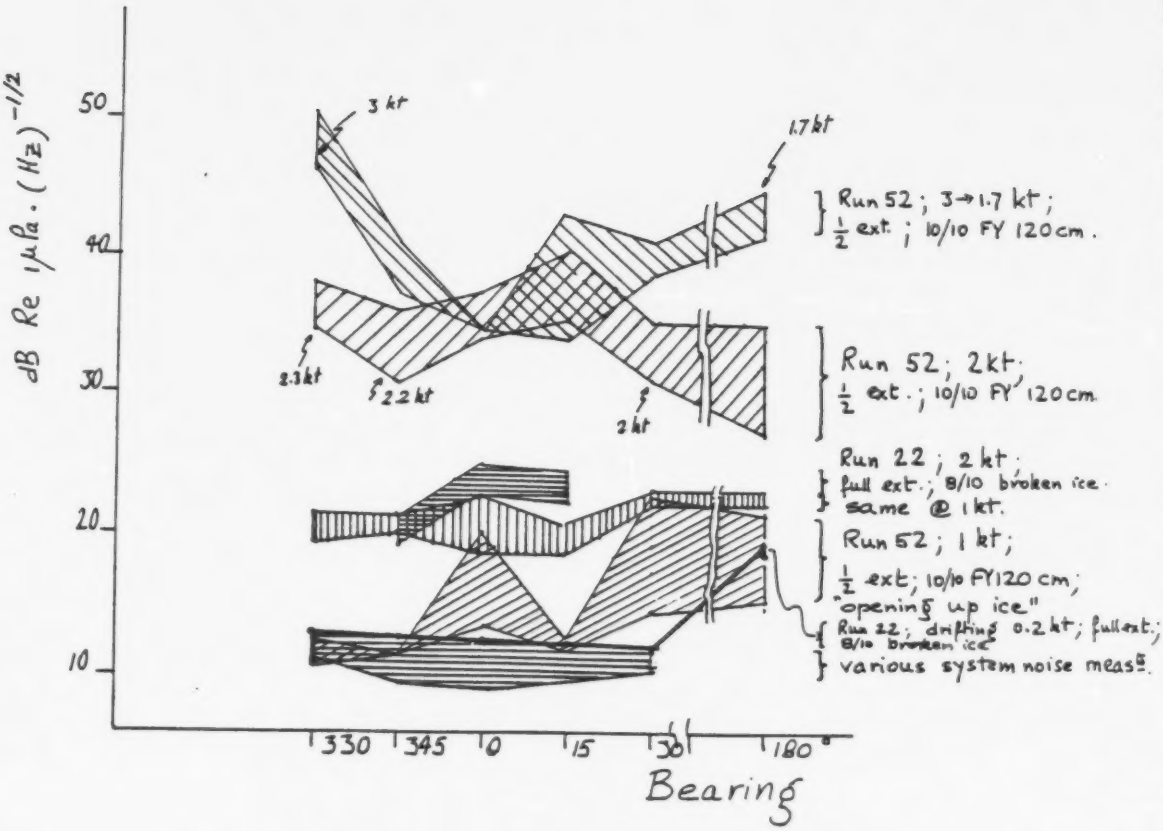


Figure 4.18 Self-noise in Icebreaking Mode

(ii) Much larger levels (35 to 45 dB Re 1μPa @ 1 to 3 knots received by the half-extended transducer) are observed when the ship is breaking solid ice (see the top two areas in Figure 4.18). If the comparison of Figure 4.17 is valid in the present case, then these levels would correspond to some 40 to 52 dB received with a fully extended transducer. However, the precise nature of the noise transmission mechanism is unknown.

(iii) A relative minimum is observed in the 3 to 1.7 kt measurement in the Figure 4.18. This may indicate a beneficial shading effect by the ship's hull towards the bow.

4.7.3 CONCLUSION

The self-noise levels reported above are recognized to be fragmentary, but should be very useful in order to calculate design parameters for an ice detecting sonar. The self-noise levels encountered when breaking solid ice are quite large, and as such will necessitate careful attention on the part of the sonar designer.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The conclusions from this work have been grouped according to a number of (partially overlapping) categories. Some of these conclusions are also based on the results of Phase I work.

5.1.1 C-TECH CDS-40A AS A RESEARCH INSTRUMENT

This sonar has proven to be a valuable and reliable tool for the purpose for which it was installed on board the M.V. Arctic, i.e. iceberg detection related measurements. The following aspects of the system were found to be particularly useful:

- easily interpretable display
- reliable operation
- large number of functions under operator's control.

Certain limitations, normal for this kind of system, have become apparent as a result of the tests.

- limited functionality of the hoist mechanism in arctic conditions
- vulnerability of the sonar transducer to ice pieces limits the testing in ice covered sea to stationary ship.
- in conditions of rapidly fluctuating returns it is difficult to keep a meaningful display and to avoid saturation of the data channel.
- strong sidelobes in the audio beam pattern sometimes render the display confusing and identification of the bearing of noise sources questionable.
- single frequency operation.

5.1.2 OBSERVATIONS AND MODELS

The following scientific results obtained during the Phase II work are related to the principal aim of this trial, to obtain sufficient data to demonstrate close range acoustic iceberg detection and to support sonar design for the same purpose.

For this reason, data acquisition and analysis were planned to make the results applicable beyond the experimental situations actually encountered. Therefore, fundamental quantities were measured and interpreted (such as target strength, echo duration etc) in addition to detection statistics.

- The empirical relationship between target strength and estimated mass of bergs discovered during Phase I of this work, was confirmed for free water bergs and verified for ice-locked bergs. Specifically, the mean target strength is observed to be similar to that of a smooth ice sphere of equal mass and negligible internal reflections.

- The observed standard deviation of the target strength estimates generally comprised 100% and 50% of their mean value.

- The peak (8 ms) target strengths estimates were found to be, on the average, some 3 dB lower than the corresponding total (energy) target strengths. This suggests that half the echo energy is contained within an 8 ms time increment (or a 6 meter range bracket).

- The average observed echo duration is bracketed as follows:

$$\frac{R}{4} \cdot \frac{2}{c} \leq \text{average echo duration} \leq \frac{R}{2} \cdot \frac{2}{c}$$

where R is the radius of a sphere of volume equal to that of the berg.

- Detection ranges in downwards refracting conditions are consistant with the iceberg echo being produced by the top half of its submerged draft. Larger detection ranges were observed for ice-locked bergs because of favourable propagation.

- Detection ranges of up to 1/2 NM were observed in open waters (propagation limited) and longer ranges of up to 1 NM for bergs in ice covered waters.

5.1.3 SYSTEM IMPLICATIONS

The following points are consequences of the observations made during this work. They are formulated in a rather general way and are thought to be essential in the design of an iceberg detecting sonar.

- Ice resistance: System must be capable of operation in ice-infested waters. This poses a difficult design problem.

- Self-noise: If operation in ice breaking conditions is desired, then the sonar will have to operate in a high self-noise environment. This may be alleviated by careful design of the system to maximize noise limited performance at a reasonable price. Steps to be taken include:

  (i) Back-to-front ratio optimization
  (ii) Directivity increase in vertical and horizontal direction
  (iii) Mechanical insulation of transducer
  (iv) Use of highest frequency compatible with maximum design range
  (v) Use of high source level and pulse compression
  (vi) Pulse to pulse integration
  (vii) Careful choice of transducer placement.

- Reverberation: Good vertical and horizontal directivity is essential to have good performance in reverberation-limited conditions (including bottom reverberation).

- Hazard classification: Information about the target contained in the echo shape and energy (target strength estimate) coupled with bearing resolution information is likely to produce a fair prediction of target size.

- Other roles: An iceberg detection system is likely to be useful for bottom feature avoidance.

- Detection range: Open water detection may well extend to some 5 km or more due to the vicinity of the first convergence zone resulting from the weak thermocline existing in the arctic waters. However this would require an operating frequency that would probably be suboptimal for closer range detection.

- Performance predictability: Experience indicates that detection ranges are predictable with reasonable accuracy as a function of target characteristics and environmental conditions.

5.2 RECOMMENDATIONS

On the basis of the understanding of the sonar close range ice hazard detection problem acquired during Phase I and II of this work, it would appear that many of the acoustic aspects of close range ice hazard detection are now understood. Certain notable exceptions, however, should not be overlooked.

- Understanding and quantification of self-noise under ice-breaking conditions.

- Confirmation and quantification of the shadowing effect produced by the ship's hull on the hull-mounted sonar.

- Confirmation of essential frequency independence of acoustic target strength of icebergs.

- Detectability of smaller ice targets in rough weather, open water, conditions.

- Confirmation of statistical independence of the radar and sonar data.

The solution of some of these questions is beyond the capabilities of the C-Tech CDS40-A sonar installed on-board of the M.V. Arctic.

In addition, and of particular importance, is the question of how to make the sonar transducer resistant to the destructive action of ice pieces passing under the hull. The solution of this problem is of decisive importance to the overall feasibility of sonar ice hazard detection in ice breaking conditions.

It is the authors' considered opinion that an adequate knowledge is now available to commence the development of an operational prototype iceberg detection sonar capable of operating in open water from a sailing ship or in ice from a stationary ship. However mastering the acoustical and mechanical aspects of operation under ice-breaking conditions will require substantial new work.

6.0 REFERENCES

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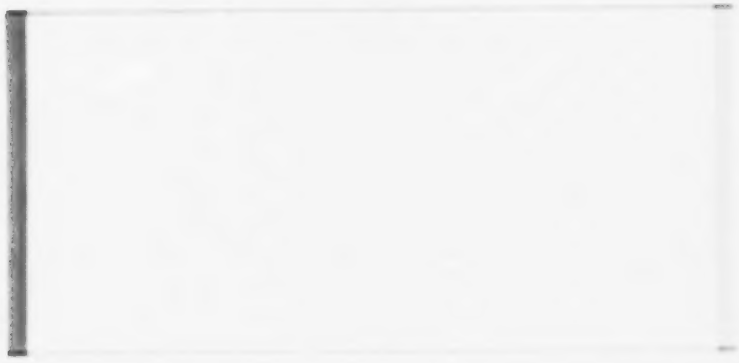

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CANARCTIC

TP-8186-E

Close Range Acoustic Ice Hazard Detection

Phase II

Volume II: Appendices

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APPENDIX 1

CLASSIFICATION, MASS AND DRAFT DETERMINATION OF ICEBERGS

APPENDIX 1

MASS AND DRAFT DETERMINATION OF ICEBERGS

For the purpose of classifying and estimating the mass of icebergs, we have used the following scheme, which, we understand are in common use amongst Canadian ice observers.

Type	Height (above sea level)	Length
growler	under 1.5 metres	under 5 metres
bergy bit	1.5 to 5 metres	5 to 15 metres
small berg	5 to 15 metres	15 to 60 metres
medium berg	15 to 50 metres	60 to 120 metres
large berg	50 to 100 metres	120 to 220 metres
very large berg	over 100 metres	over 220 metres

Bergs are also described according to shape and/or the average height to draft ratio, which can be as small as one to eight (seven-eights submerged). Following is the shape classification of icebergs used by the International Ice Patrol:

Type	Ratio	Description
blocky or tabular	1:5	rather flat on top with steep vertical sides
rounded or domed	1:4	large, smooth and rounded on top
picturesque	1:3	varied and irregular
pinnacled or ridged	1:2	large central spire or pyramid with one or more spires surrounding
horned and winged or drydock	1:1	eroded such that a large U-shaped slot is formed near or at water level with twin columns or pinnacles

These ratios were derived from actual measurements of icebergs south of Newfoundland.

A reasonable estimate of the total iceberg mass in metric tons can be approximated by multiplying the above water portions of height times the width times the length, all in metres, and then multiplying this product by a factor of 3.01. This factor partly accounts for the density difference between sea water and fresh water, and partly for the average shape and mass distribution. Considerable variation occurs in berg size according to geographical location. Some of the largest size bergs are in the 8.5 million ton size and are found near the source region. However, near latitude 48N, a one million ton berg is exceptional with most being less than half that figure.

APPENDIX 2
THE SONAR EQUATION, TARGET STRENGTH AND BACKGROUND LEVELS

APPENDIX 2

THE SONAR EQUATION

For an active sonar system, the intensity of an echo received from a target is given in logarithmic form by the basic equation:

$$EL = SL - 2TL + TS \qquad (A2.1)$$

where EL is the echo level in dB re 1 μPa*
SL is the source level in dB re 1 μPa at 1 m
2TL is the two way transmission loss in dB
and TS is the target strength in dB per square metre

Equation A2.1 indicates that echo level will increase if the source level increases, and decrease if the transmission loss increases. The term Target Strength is the only acoustic parameter associated with the target that affects echo amplitude. Thus if both source level and transmission loss were constant, or known, then the echo level would reflect the target strength directly. Target strength can be defined as the ratio of the effective acoustic cross sectional area of a target and a standard area normally in square metres. This definition assumes that the whole target is insonified by the sonar pulse.

In effect, the target strength for a uniform sphere is given by:

$$\text{Target Strength (TS)} = 10 \log \frac{I_R}{I_I} = 20 \log \frac{a}{2} \qquad (A2.2)$$

where a = Sphere Radius
I_I = Incident Intensity
and I_R = Re-radiated Intensity at a distance of 1 m

---

*deciBels relative to a pressure level of one microPascal (μPa)

Target strength combines effects that contribute to an echo into one parameter. Intuitively the larger a target, the greater the target strength will be. However, target strength does not take into account target shape or composition. Therefore if these are also variable, then the simple relationship involving size will have to include shape, orientation and composition terms. The geometrical factors such as range are included in the transmission loss.

Use of Sonar Equation in the Estimation of Target Strength

Equation A2.1 can be rearranged to give the target strength in terms of the other parameters:

$$TS = EL + 2TL - SL \qquad (A2.3)$$

If target strength is then to be derived from a measured echo level, the other parameters TL and SL in equation A2.3 must be known or able to be determined.

Source level is a basic specific parameter for most sonar systems and calibration information is usually available or can be measured. Under ideal conditions and with knowledge of the range and frequency, transmission loss can be computed. Thus, by means of a direct measurement of the echo level and with knowledge of the sonar system receiving gains, a value of target strength can be obtained.

Since the measurement of echo level is made from an electrical signal, the final formula for target strength includes additional parameters. Thus:

$$\text{Target Strength } TS = 20 \log V - S - G + TL - SL \qquad (A2.4)$$

where echo level EL has been replaced by

$$EL = 20 \log V - S - G$$

where V is the measured voltage at the output of the receiving amplifier.

S is the receiving transducer sensitivity in dB relative to 1 V/μPa, in the target direction (thus including effects of the transducer directivity)

and G is the gain of the receiving amplifier in dB

Thus, in summary:

$$TS = 20 \log V + 2TL - (SL + S + G)\ dB \qquad (A2.5)$$

Measured Parameter — Transmission Effect — System Parameters

Assuming the system parameters are constant (and known) during the course of the data acquisition program, then a measurement of a voltage and the estimation of a two way transmission loss will allow target strength to be obtained.

Estimates of Transmission Loss

The transmission loss for sea water can either be calculated or extracted from a graph.

In terms of pressure level, the one way transmission loss is given by (Urick, 1975):

$$TL = 20 \log R + \alpha R\ dB$$

assuming spherical spreading and R is range in metres. Thus, the two way transmission loss:

$$2\ TL = 40 \log R + 2\alpha R\ dB \qquad (A2.6)$$

where R is the range (metres) and α is the absorption coefficient (dB/m) at the particular frequency.

At 36 kHz α = 0.01 dB/m

Therefore, $2TL = 40 \log R + 0.02 R$ dB (A2.7)

In addition, Appendix 5 gives transmission losses calculated on the basis of ambient conditions prevalent at the place of the tests, and taking into account focussing effects of the medium. From these results, it was concluded that equation A2.7 gives an estimate of the transmission loss which is probably more reliable than that resulting from the more detailed propagation calculations.

Total vs Peak Target Strength

The target strength as defined above refers to the reflective properties of the whole sonar target. In a number of situations it is meaningful and useful to define the TS_τ peak target strength over a specified time τ, as the maximum over the echo duration of the target strength measured for a τ seconds "slice" of the echo. For this definition to be applicable, it is necessary that the time resolution of the transmitted impulse be better (i.e. shorter) than τ seconds.

In the case of the signal processing hereunder defined,

τ = 8ms (A2.8)

as 8ms is the longest pulse which was commonly used in these echo-ranging trials.

Reasons for calculating this "8ms target strength" are given below:

- It gives a measure of echo peakiness common to most pulses used during trials.
- It is appropriate for the definition of (8ms) peak-detecting processor, the performance of which may be superior or complementary to that of the energy detecting devices.
- It is a measurement which is less sensitive to contamination by multipath effects because it tends to select the strongest arrival.

Importance and Estimation of Noise Level and Reverberation Scattering Strength

Any practical sonar system which detects the presence of a signal (eg. an iceberg echo), has to operate within the naturally occurring, acoustic background, which tends to mask the desired signal or contribute false returns. It is therefore meaningful (Urick 1975 Chapter 2, 12 and 13) to characterize the detection performance of a sonar system in terms of signal-to-background ratio (SBR).

In logarithmic terms, (deciBels):

$$SBR = EL - BML \qquad (A2.9)$$

where: EL is the "Echo Level" or level of the return signal

BML is the (acoustic) background masking level, generally in the frequency band of the sonar (dB Re 1 µPa)

The dominant background masking level of an active sonar can be caused by noise or reverberation.

Noise is the acoustic energy received by the sonar in the absence of any transmission. In this case, the noise is dominated by self-noise, i.e. the noise power generated by the ship which is received by the ship-mounted sonar. Specific mechanisms generating self-noise include engine noise, flow noise at the transducer and elsewhere, propeller cavitation, and, most important, the noise caused by the icebreaking action of the hull. Self-noise is usually defined and measured using a specific sonar transducer and combination of ship parameters.

Self-noise level (SNL) is expressed in dB Re 1 µPa and can be measured in a manner similar to the target strength, with the exception that the sonar is set in the receive only mode.

Reverberation refers to that portion of the sound received by an active sonar system which is caused by scattering towards the receiver of part of the acoustic energy transmitted by the sonar. The sum total of the contributions from all scatterers is called reverberation (= clutter, in radar).

The reverberation is specified in terms of its Volume Scattering Strength and Surface Scattering Strength.

Volume reverberation refers to that portion of the reverberation caused by scatterers in the volume or body of the sea.

The **Volume Scattering Strength** S_v is expressed in dB Re 1μPa and is the target strength of one cubic meter of ocean volume.

Surface reverberation is produced by scatterers located on or near the sea surface as is the case for reverberation caused by sea ice.

Surface reverberation can be characterized in a manner independent of the sonar system used. Its dependence on environment, geometry and frequency is given by the **Surface Scattering Strength** S_s, expressed in dB Re 1μPa, which is the target strength of one square meter of ocean surface.

$S_s(\tau)$ can be estimated by equation A2.10 (assuming that the reverberation level is dominated by surface reverberation).

$$S_s(\tau) = (\text{Reverberation TS}) - 10 \log A \qquad \text{(A2.10)}$$

where:

Reverberation TS: is the apparent target strength corresponding to the received reverberation level τ seconds after transmission

A: is the surface area insonified by the sonar pulse τ seconds after transmission.

A more detailed treatment of the above concepts can be found in Urick (1975) Chapter 8.

APPENDIX 3
DIARY OF EVENTS

DATE AND PLACE

The trials took place during the passage of the M.V. Artic between Nanisivik and Antwerp (6 July - 18 July, 1986). The measurements on the ice targets were carried out around the following geographical positions, at the GMT dates and times specified below:

	Sound Speed Profile	Depth
6 July 22:00 - 7 July 07:30		
74° 05'N, 80° 03'W (Lancaster Sound)	A	800 m
7 July 19:30 - 8 July 06:00		
73° 35'N, 70° 49'W (Baffin Bay)	B	1400
8 July 17:30 - 9 July 07:30		
73° 10'N, 64° 39'W (Baffin Bay)	C,D	2200
9 July 15:00 - 9 July 24:00		
72° 51'N, 60° 33'W (Baffin Bay)	X	400
10 July 06:00 - 10- July 13:30		
72° 30'N, 58° 18'W (Baffin Bay)	E	-200

A total of 48 hours of dedicated ship time were devoted to the trials.

LOGISTICS, INSTALLATIONS ON BOARD: CAPTAIN, CREW AND NON-SHIP PERSONNEL

LOGISTICS

A serious problem was encountered when it became known to the author four days prior to shipping the test equipment to Antwerp that an export license was mandatory to have the test equipment "exported" to Belgium for the sole purpose of being transferred on-board of the M.V. Arctic (a Canadian ship) in Antwerp. An export license was promptly requested for the said equipment, which was not received until after the end of the tests. Fortunately, due to a few day's delay in the ship's schedule, it was possible to send most of the equipment to Nanisivik to be loaded on the ship in this Canadian port, which made the export license unnecessary.

Prior to leaving Nanisivik, the test equipment was seen by the Nanisivik RCMP Officer (acting as a customs' agent) leaving Canada. This facilitated the reimportation formalities when the equipment was sent back from Belgium to Canada after completion of the trials.

INSTALLATION ON BOARD

An area on the bridge was designated for the iceberg detection test equipment. This proved very convenient, as the sonar (C-Tech CDS-40A) console is located on the bridge and most ship manoeuvres around berg targets were commanded from the bridge.

After completion of the data acquisition phase, data reduction was started in the laboratory located on the upper deck of the ship, to confirm the data quality.

CAPTAIN, CREW AND NON-SHIP PERSONNEL

We received outstanding cooperation and support form the ship's Captain T.D.A. Murphy, the Ice Pilot D. Schofield, as well as from the officers and crew of the M.V. Arctic, in particular during the often difficult and unusual manoeuvres necessitated by these trials.

Excellent support was provided by the ice observers P. de Bastiani (Canarctic) and B. Broughton (Norland) in target tracking and environment tracking and characterization.

Finally, the trials would have probably been cut short without the dedicated work of N. Van Beek (C-Tech) in manually operating the sonar hoist.

NARRATIVE OF TRIALS

(Unless otherwise indicated, dates and times are GMT)

June 23 and 24, 1986

CAL party (de Heering, Sutcliffe) arrives on board M.V. Arctic in Antwerp and completes installation and test of data acquisition hardware. At 10:00 (local) on the 24th, Van Beek (C-Tech) determines that the sonar transducer is defective, and Sneyd (Canarctic) directs CAL party to return to Ottawa. Ship leaves Antwerp at about noon (12:00) (local) for Nanisivik.

June 30, 1986

Sneyd, having completed arrangements with C-Tech for sonar overhaul, directs CAL party to join the ship in Nanisvik on July the 4th.

July 4 & 5, 1986

M.V. Arctic arrives in Nanisivik at 09:00 local. CAL party and C-Tech party (Van Beek, Poletti) board M.V. Arctic. Final tests of CAL equipment are carried out (in particular, of the sound velocity profile). Sonar repair is completed by C-Tech party on the evening of the 4th (substitution of defective transducer).

July 6 & 7, 1986

M.V. Arctic leaves Nanisivik at 05:00 local. At 22:00 hours, start of tests.

The ice cover is less than one-tenth.

The following suite of runs is carried out. This suite is essentially repeated with different targets and in different environmental conditions and geometries on subsequent days.

- Iceberg echo acquisition runs (Alfa) are carried out on ice targets 1 and 2 (medium and small bergs), to provide data for comparison with previous results[1].

- Propagation runs (Charlie) are carried out for calibration purposes with pinger source suspended at stem of ship.

- Reverberation runs (Bravo) are carried out in four representative azimuthal directions for comparison to ice covered case.

- Ship's self noise runs (Delta) are carried out with sonar transducer fully extended and half extended, to provide basis for comparison for the later noise measurements carried out in icebreaking mode with half-extended transducer.

- In addition, one sound velocity profile was carried out, together with the other appropriate environmental observations. Iceberg targets were photographed from representative aspects.

July 7 & 8, 1986

(Baffin Bay) Work starts at 20:30 in very close packed 1st year ice. This ice cover allows the ship to manoeuvre with relative ease to and around bergs.

- Runs Alfa are carried out on Target 3 (large, picturesque), 4 (small, tubular) and Target 5 (small, undefined shape berg), with detection ranges significantly larger than those experienced in open water for similar targets.

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[1]Op. cit.

- Run Charlie is not carried out as it is impossible to walk on ice.

- Run Bravo is carried out in the vicinity of targets.

- Runs Delta are carried out at one an two knots with fully extended sonar transducer as the ship's master advises that pieces of loose ice are unlikely to reach transducer at these speeds in the prevailing ice cover.

- Sound velocity and environmental observations are carried out.

July 8 & 9, 1986

(Baffin Bay) Ship has been proceeding the whole day of the 8th in solid ice cover in fog. Several bergy bits undetected on radars are seen starboard and port of the ship's trajectory. At 19:00, brief stop to consider whether to ping at small berg in solid ice. It is decided not to do so since this is an isolated target which, therefore hardly justifies the time expense need for the environmental measurements.

At 19:40, stop near medium picturesque berg (Target 6).

- Runs Alfa carried out at various ranges.

- Runs Bravo carried out in vicinity of berg.

- Run Charlie carried out with pinger deployed through-the-ice by ice party. No detectable arrivals are received at 500 and 200 m. Later, Charlie run carried out with pinger on ship's stern, where very weak arrivals are received. This, together with detection anomalies observed during the above Alfa runs and received levels anomalies during the Bravo runs, remains unexplained, as the problem corrects itself at a later time. Observed effects appear to be consistent with temporary fault in one of the sonar gain controls. Sonar hoist problems are experienced as of this day and until the end of trials, and manual or semi-manual hoist operation is carried out by VanBeek.

July 9, 1986

We proceed through 10/10 first year ice, later through medium to big first year ice flows separated by large leads, often created by the icebreaking.

At about 14:30, we sight a bear track running parallel to the ship's track a few meters.

At 15:30 we are in position in 7/10 ice cover in diminishing visibility in sight of several bergs.

Several runs Alfa are carried out on Target 7 (small berg, almost invisible in thick fog).

- Runs Bravo and Charlie are also carried out, the latter both with the pinger source at the ship's stern and lowered through leads in the ice at two different ranges by an ice party.

- Run Delta is carried out in ice breaking mode with the transducer hoist half extended, at speeds of about one and two knots.

Environmental observations are carried out.

No other targets are pinged as the visibility is very low.

July 10, 1986

Visibility is excellent at the time of beginning of work (06:30) and deteriorating thereafter. Several bergs are visible in 1/10 ice cover, dropping to almost 0/10 later in the day.

Alfa runs are carried out on Target No. 8 (small weathered) No. 9 (large blocky), No. 10 (domed bergy bit) and No. 11 (medium picturesque, rounded) berg.

Bravo runs are carried out at several azimuthal directions.

Delta run carried out at speeds of 10-11 knots, with transducer fully and half extended.

Environmental measurements are carried out.

July 11-18, 1986

Baffin Bay to Antwerp. Limited, mostly quality control, work on the data is carried out, as permitted by the sea state.

APPENDIX 4
DATA SUMMARY

APPENDIX 4
Data Summary

Run No.	Date	GMT Start	GMT End	Run Type	Comments
1,2	July 6,7	23:10	00:10	Alpha	Iceberg #1
3	July 7	02:43	02:55	Charlie	Propagation
4,5		03:30	05:00	Delta	Noise
6,7		05:38	06:41	Alpha	Iceberg #2
8,9		20:05	21:52	Alpha	Iceberg #3
10		22:00	22:14	Bravo	Reverberation
11-13	July 7,8	23:10	00:35	Alpha	Iceberg #3
14-21	July 8	02:49	05:01	Alpha	Icebergs #4, #5
22		05:25	05:33	Delta	Noise
23,24		22:55	23:21	Alpha	Iceberg #6
25-28	July 9	01:10	01:23	Charlie	Propagation
29-33		04:15	07:00	Alpha	Iceberg #6
34		07:15	07:17	Delta	Noise
35-46		16:16	17:57	Charlie	Propagation
47		18:00	19:00	Delt/Brav	Noise and Reverb
48-51		19:20	22:38	Alpha	Iceberg #7
52	July 9,10	22:35	23:57	Delta	Self Noise
53-55	July 10	06:55	07:33	Alpha	Iceberg #8
56,57		09:55	10:58	Alpha	Iceberg #9
58		11:29	11:34	Alpha	Iceberg #10
59,60		11:59	12:42	Alpha	Iceberg #11
61		12:55	13:17	Alpha	Noise

DATA SUMMARY

ICEBERG NO.	: 1
POSITION	: 74 10 N, 80 07 W
TYPE	: Medium Tabular
ESTIMATED DIMENSIONS	: Height above waterline: 12 m Length at waterline: 113 m Width at waterline: 113 m Estimated draught: 60 m Estimated tonnage: 461 kT
DATE	: July 6,7, 1986
GMT	: Start: 23:10 End: 00:10
ENVIRONMENT	: Sea State: Moderate Ice Cover: N/A Wind Speed: 25 knots Water Depth: 800 m Sound Speed Profile Ref: A

RUN NO.	COMMENTS
1,2	: Open water, haze, pieces of first year ice drifting

TARGET STRENGTH MEASUREMENTS

Number of Estimates: 37
Observed at: 200-540 m
Max. Observed Detection Range: 650 m

	Peak Value (8ms)	Total Energy
(T.S. - sigma), dB	7.4	9.5
Mean Target Strength, dB	11.8	15.3
(T.S. + sigma), dB	14.0	17.7

ICEBERG #1

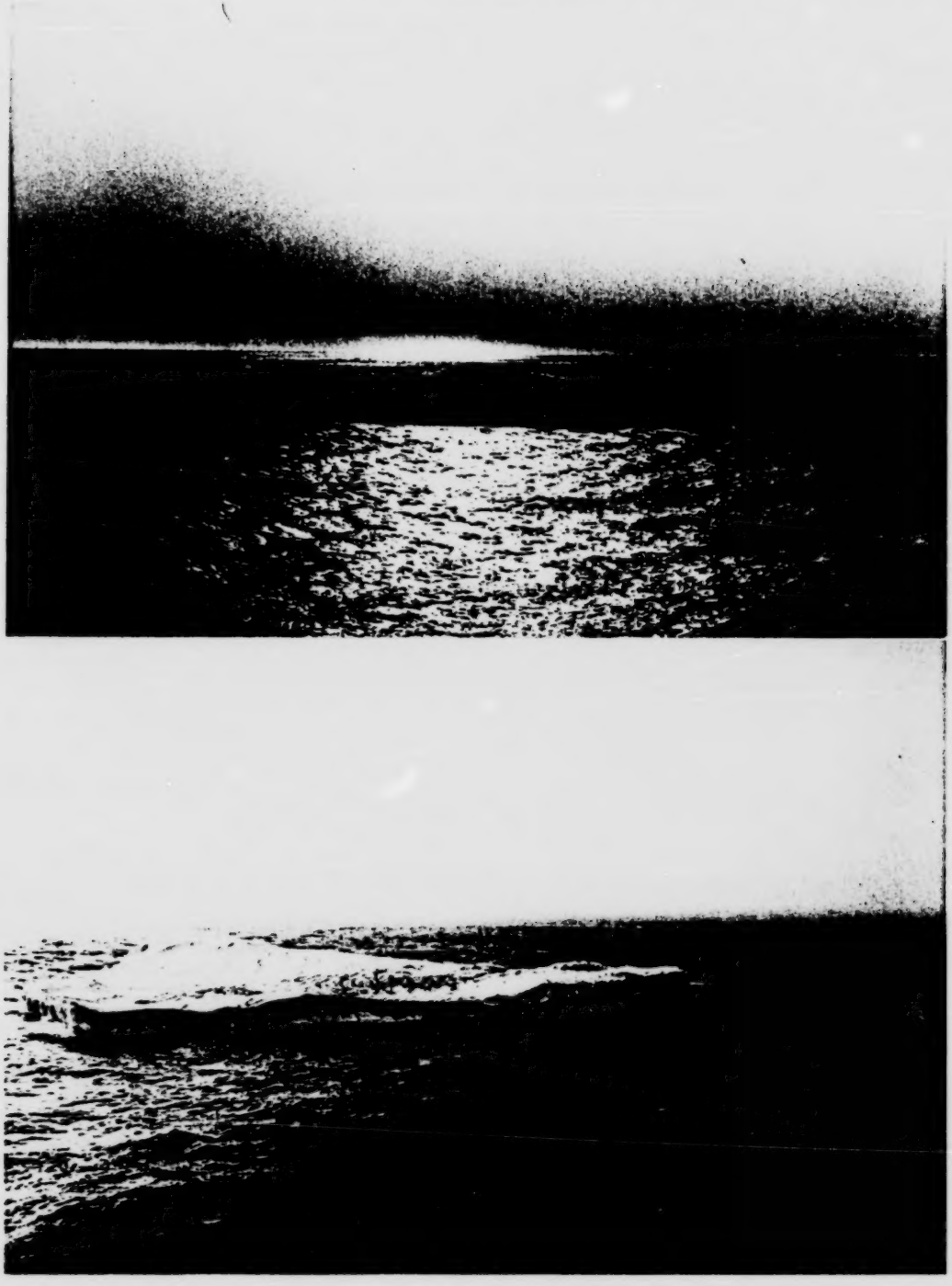
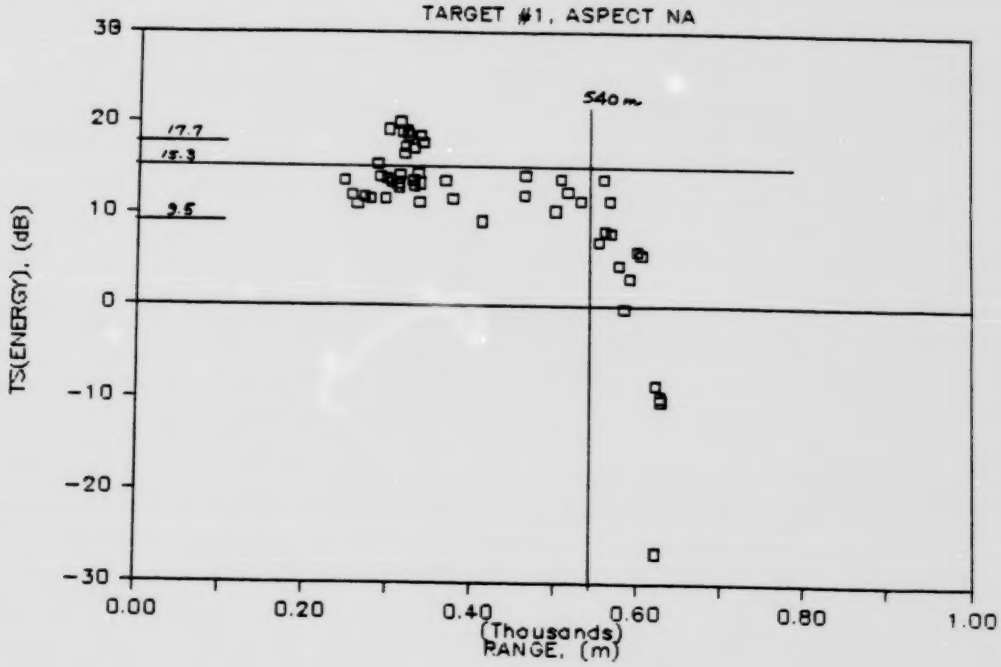
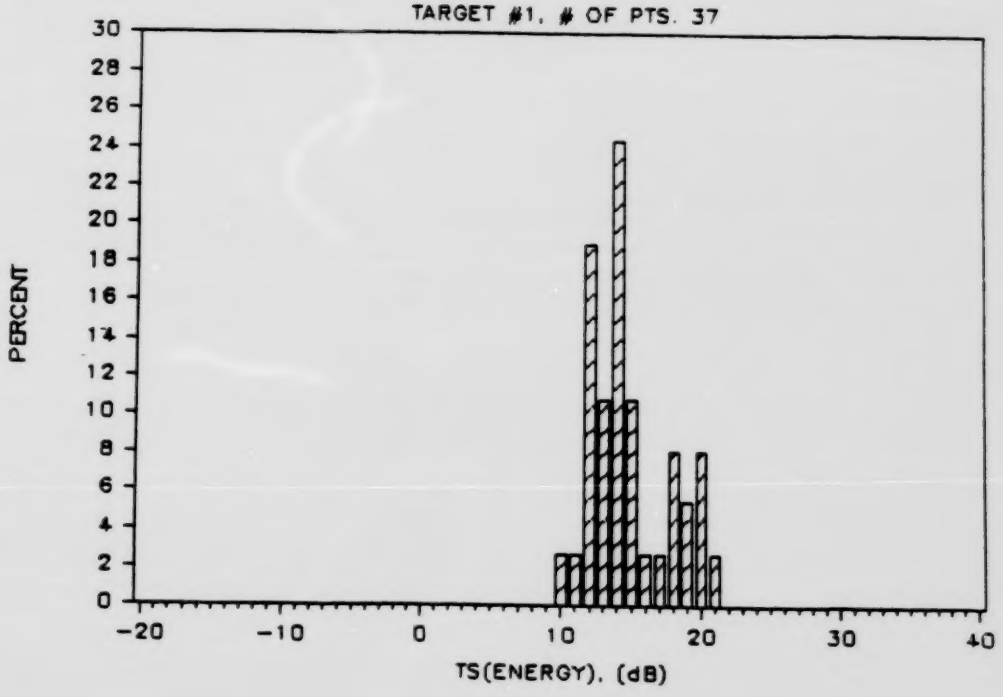
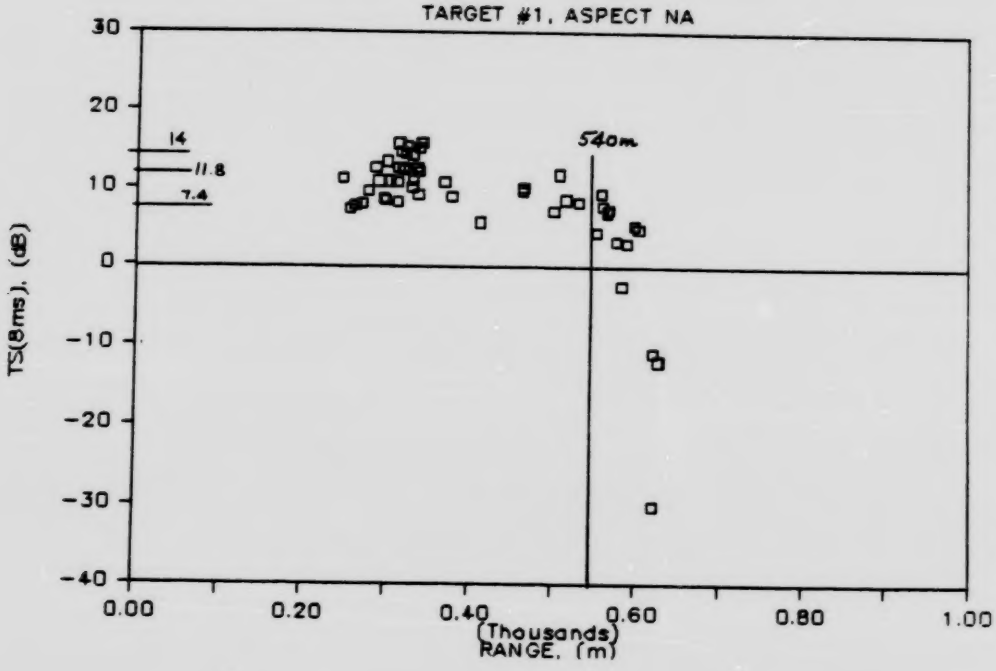
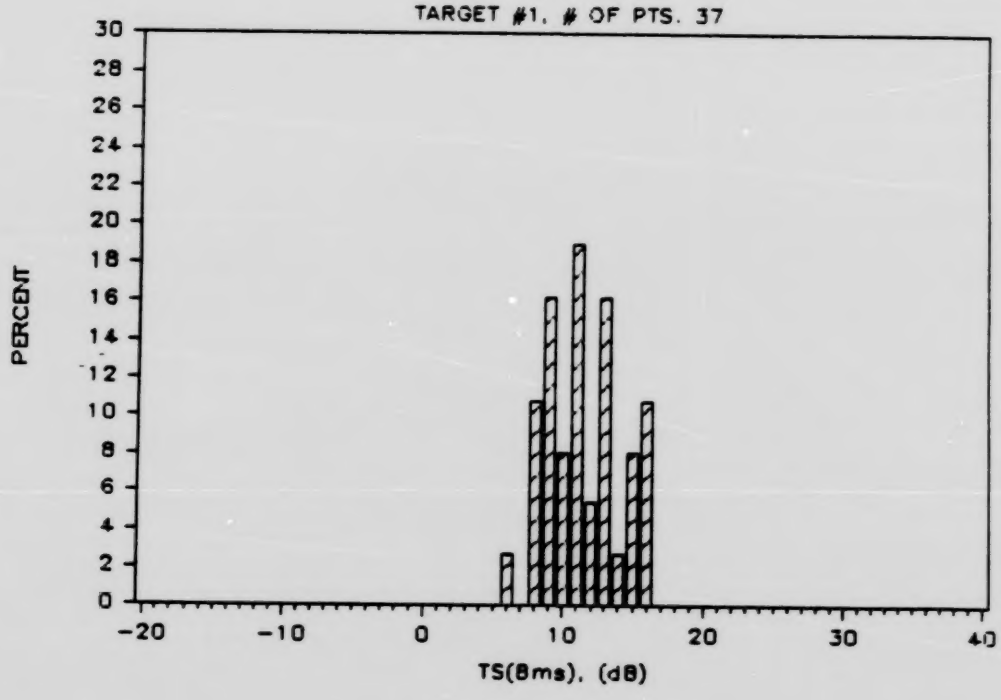


PLATE A1


TARGET #1, ASPECT NA
540 m
17.7
15.3
9.5
TS(ENERGY), (dB)
30
20
10
0
-10
-20
-30
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE, (m)


TARGET #1, # OF PTS. 37
PERCENT
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
TS(ENERGY), (dB)


TARGET #1, ASPECT NA
30
20
10
0
-10
-20
-30
-40
14
11.8
7.4
540m
TS(8ms), (dB)
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE, (m)


TARGET #1, # OF PTS. 37
PERCENT
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
TS(8ms), (dB)

DATA SUMMARY

ICEBERG NO.	: 2
POSITION	: 74 05 N, 80 03 W
TYPE	: Small, domed, weathered
ESTIMATED DIMENSIONS	: Height above waterline: 14 m Length at waterline: 49 m Width at waterline: 45 m Estimated draught: 52 m Estimated tonnage: 86 kT
DATE	: July 7, 1986
GMT	: Start: 05:38 End: 06:41
ENVIRONMENT	: Sea State: 1m waves/6 sec Ice Cover: N/A Wind Speed: 16 knots Water Depth: 800 m Sound Speed Profile Ref: A

RUN NO.	COMMENTS
6,7	: Open water, pieces of first year ice drifting

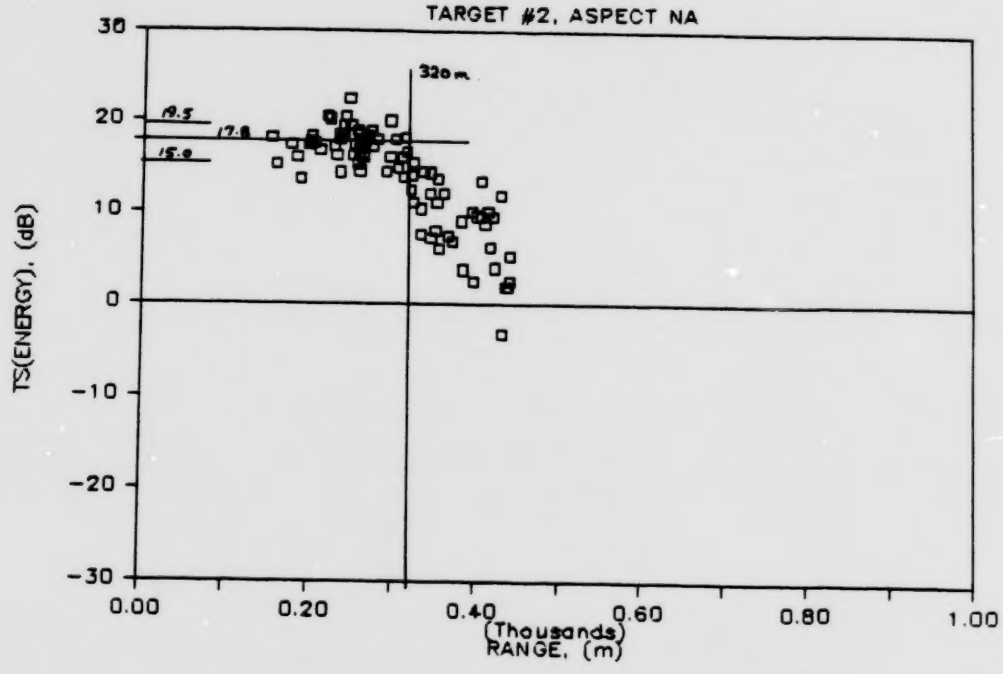
TARGET STRENGTH MEASUREMENTS

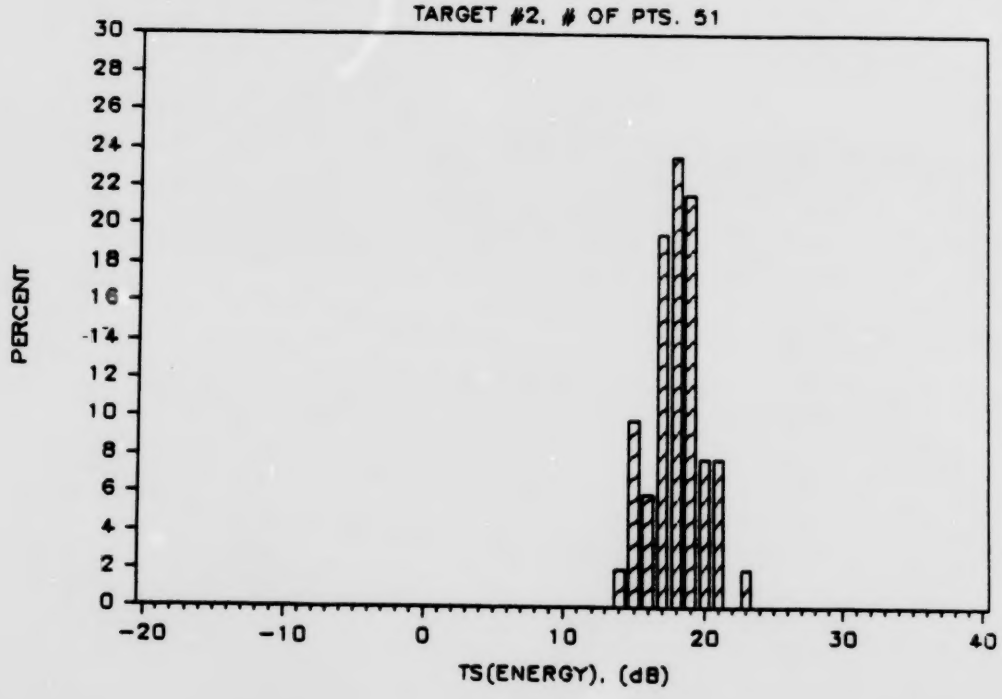
Number of Estimates: 51
Observed at: 100-320 m
Max. Observed Detection Range: 450 m

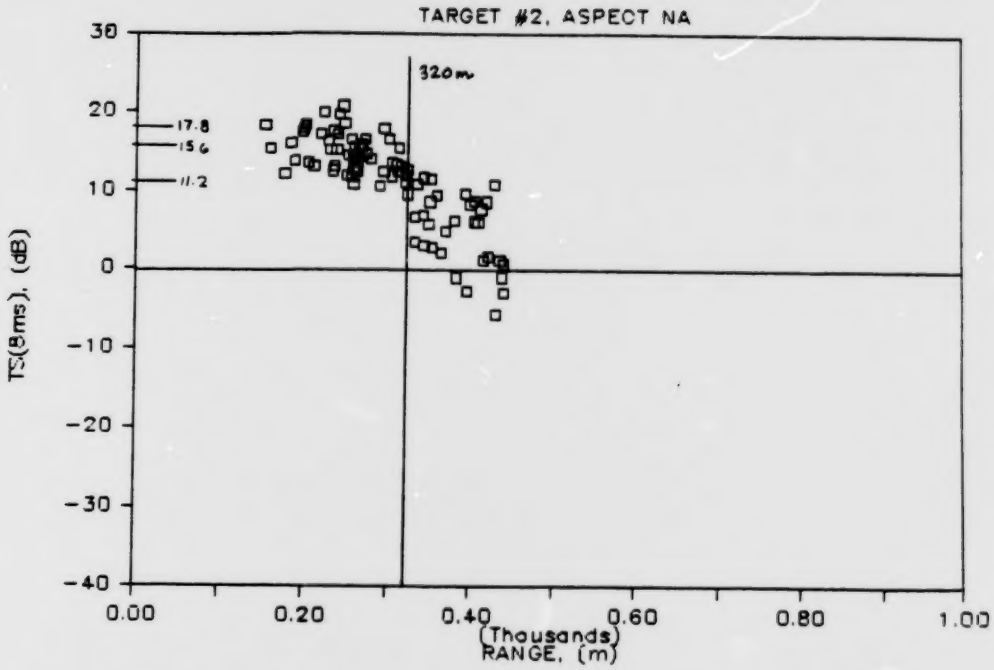
	Peak Value (8ms)	Total Energy
(T.S. - sigma), dB	11.2	15.0
Mean Target Strength, dB	15.6	17.8
(T.S. + sigma), dB	17.8	19.5

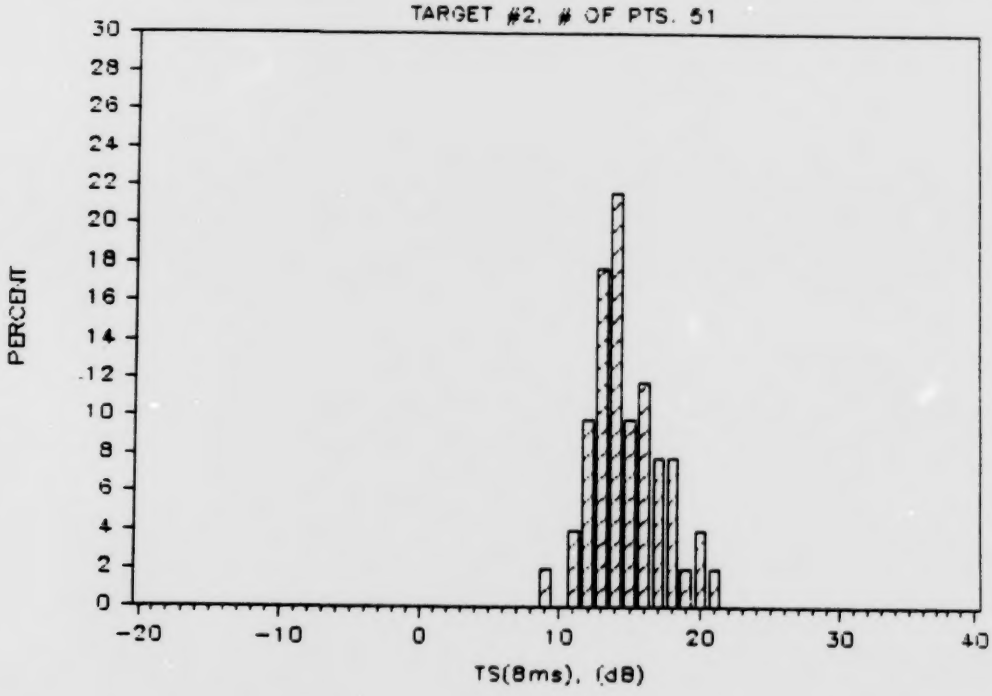
ICEBERG #2

PLATE A2


TARGET #2, ASPECT NA
320 m
19.5
17.8
15.0
TS(ENERGY), (dB)
30
20
10
0
-10
-20
-30
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE, (m)


TARGET #2, # OF PTS. 51
PERCENT
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
TS(ENERGY), (dB)


TARGET #2, ASPECT NA
320m
17.8
15.6
11.2
TS(8ms), (dB)
30
20
10
0
-10
-20
-30
-40
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE, (m)


TARGET #2, # OF PTS. 51
PERCENT
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
TS(8ms), (dB)

DATA SUMMARY

ICEBERG NO.	: 3
POSITION	: 73 38 N, 70 47 W
TYPE	: Large Picturesque
ESTIMATED DIMENSIONS	: Height above waterline: 22 m Length at waterline: 176 m Width at waterline: 130 m Estimated draught: 105 m Estimated tonnage: 1.45 MT
DATE	: July 7,8, 1986
GMT	: Start: 20:05 End: 00:35
ENVIRONMENT	: Sea State: Ice Cover: 8/10 Wind Speed: 9 knots Water Depth: 1400 m Sound Speed Profile Ref: B

RUN NO.	COMMENTS
8,9,11 12,13	: Close packed first year ice

TARGET STRENGTH MEASUREMENTS

Number of Estimates: 40
Observed at: 200-1400 m
Max. Observed Detection Range: 1400 m

	Peak Value (8ms)	Total Energy
(T.S. - sigma), dB	sigma > T.S.	sigma > T.S.
Mean Target Strength, dB	19.6	24.1
(T.S. + sigma), dB	23.7	28.8

ICEBERG #3

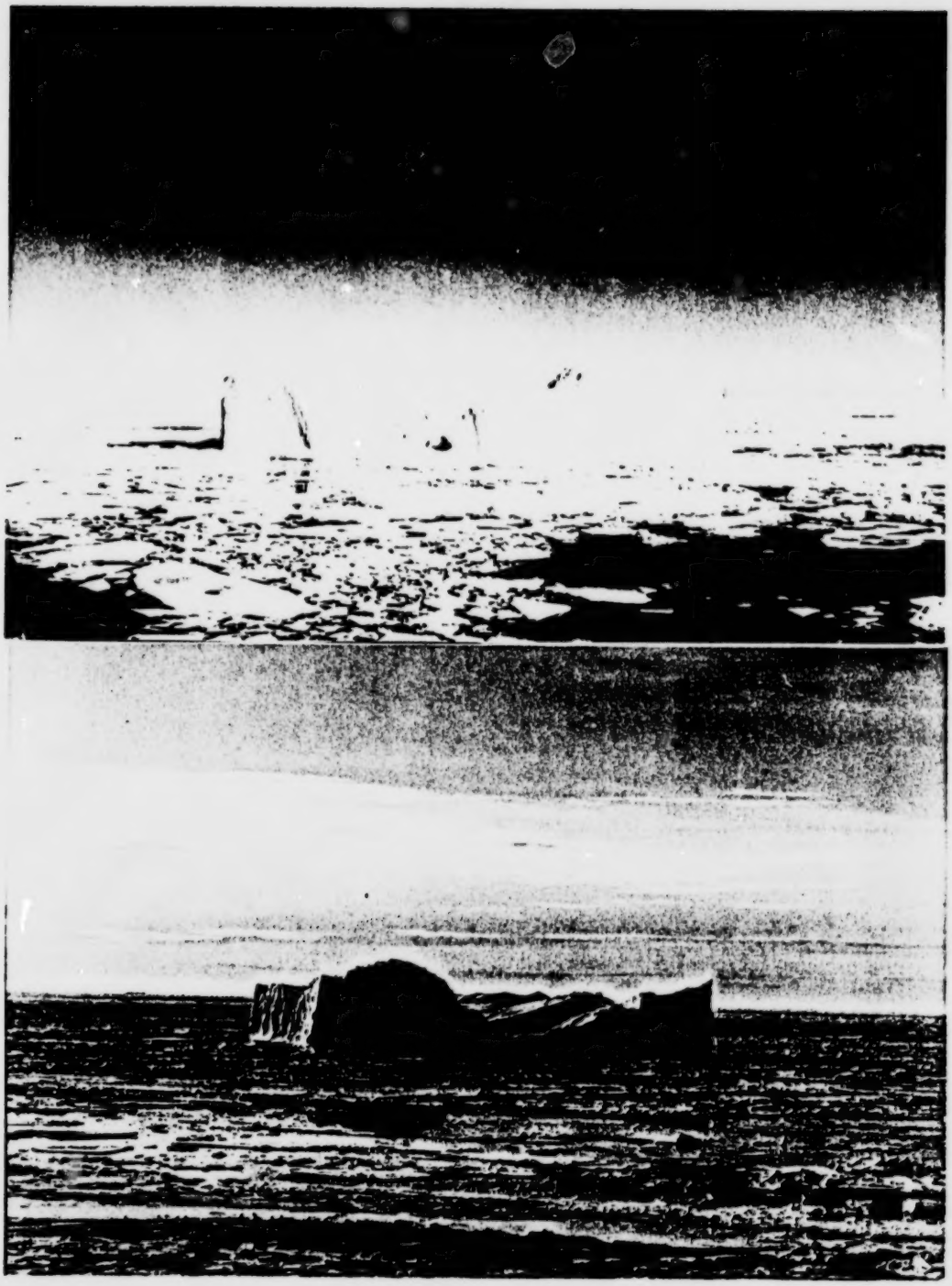


PLATE A3

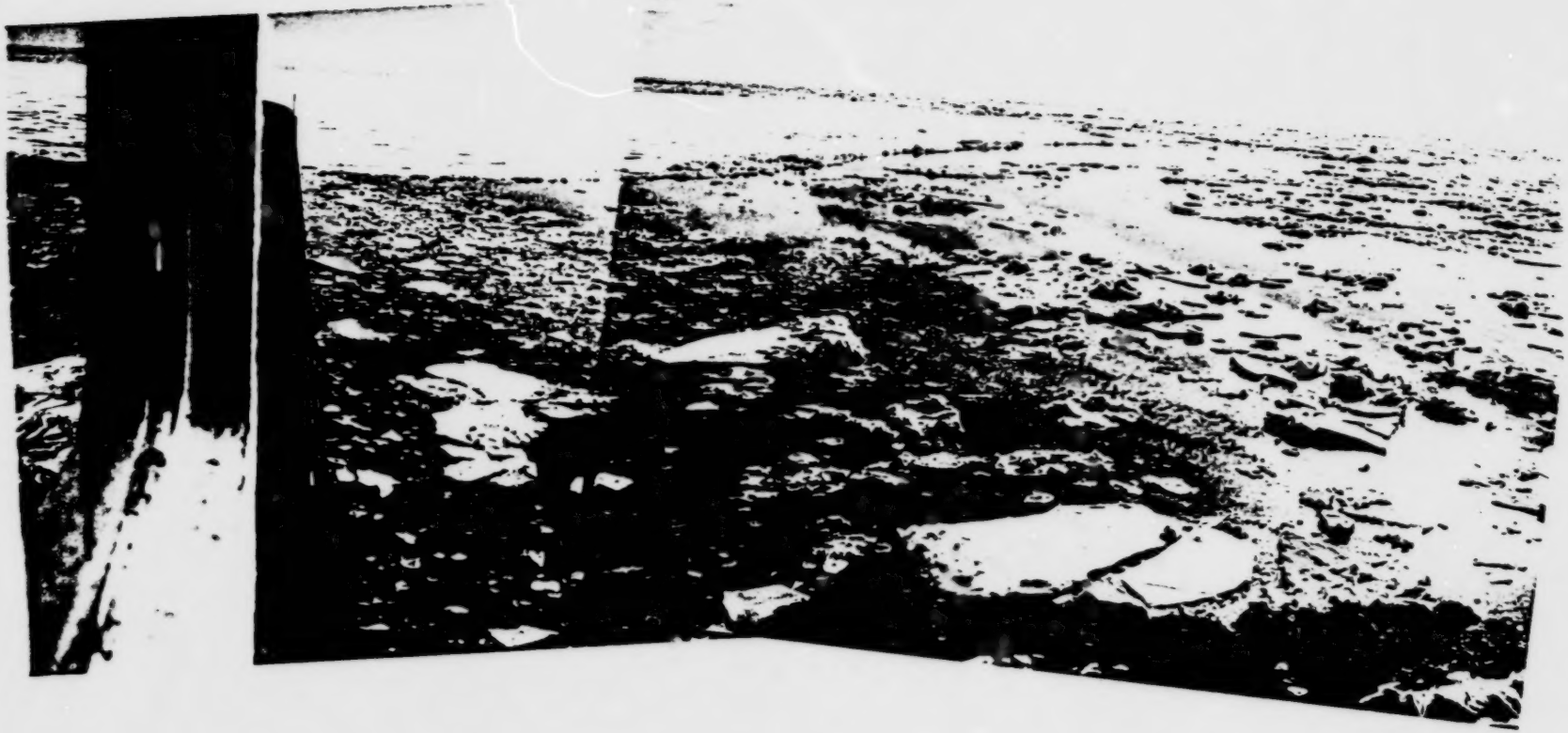
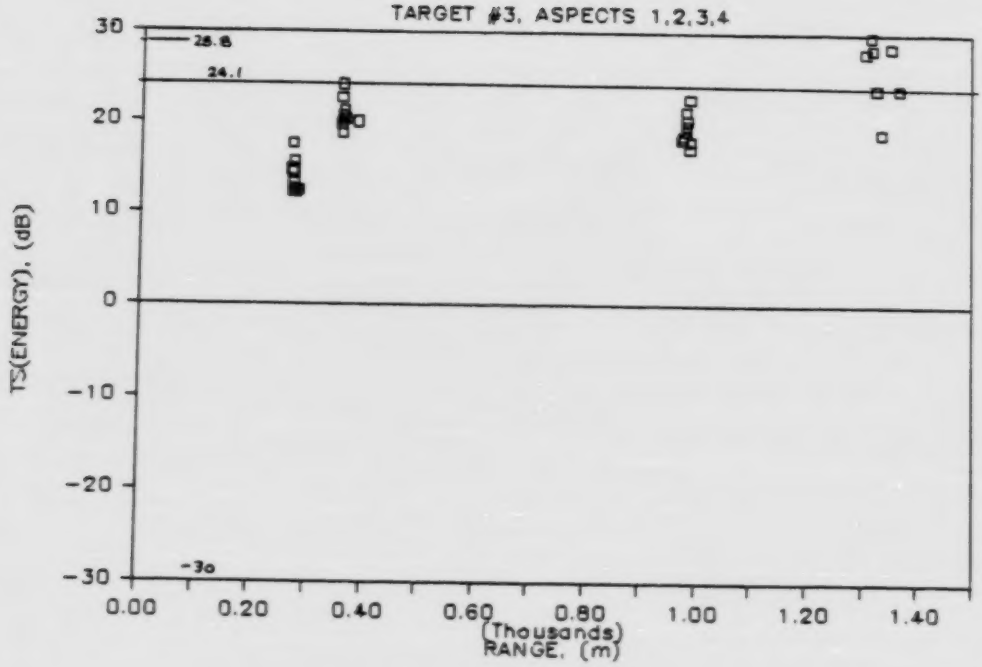
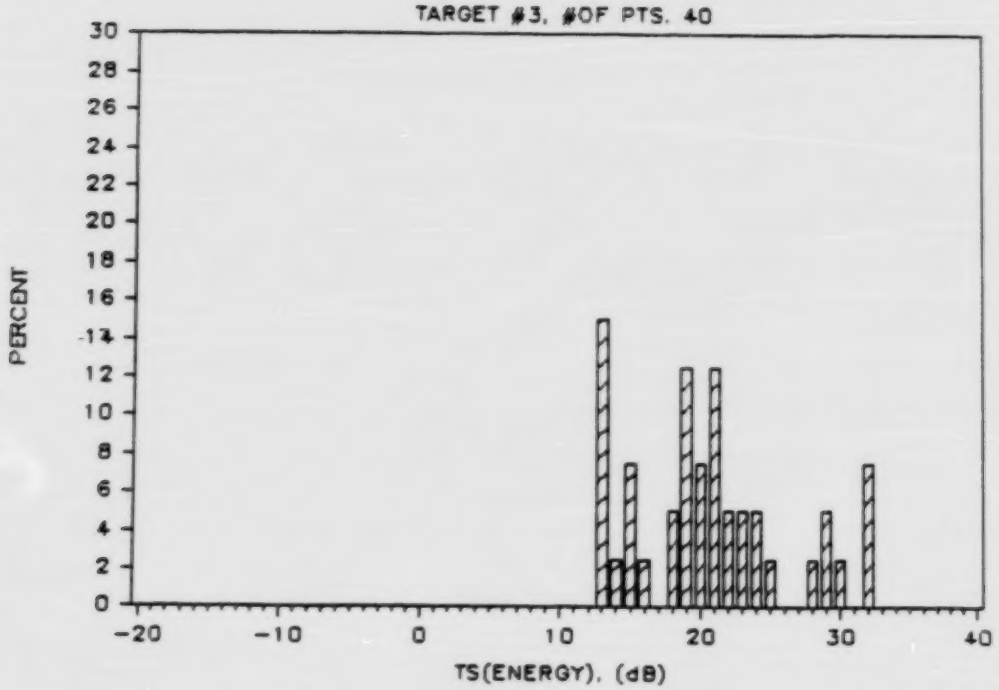
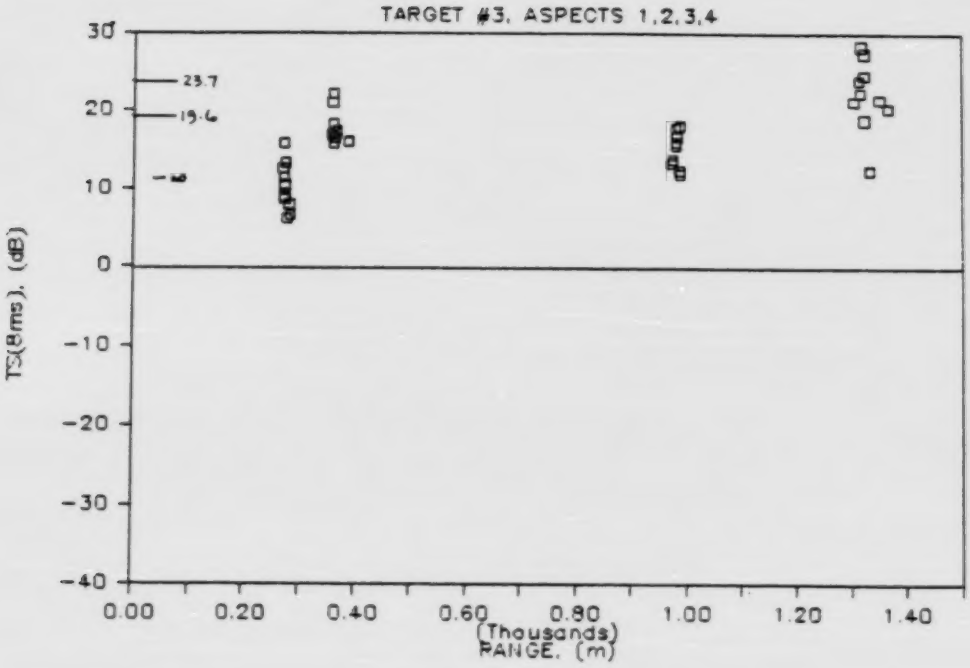


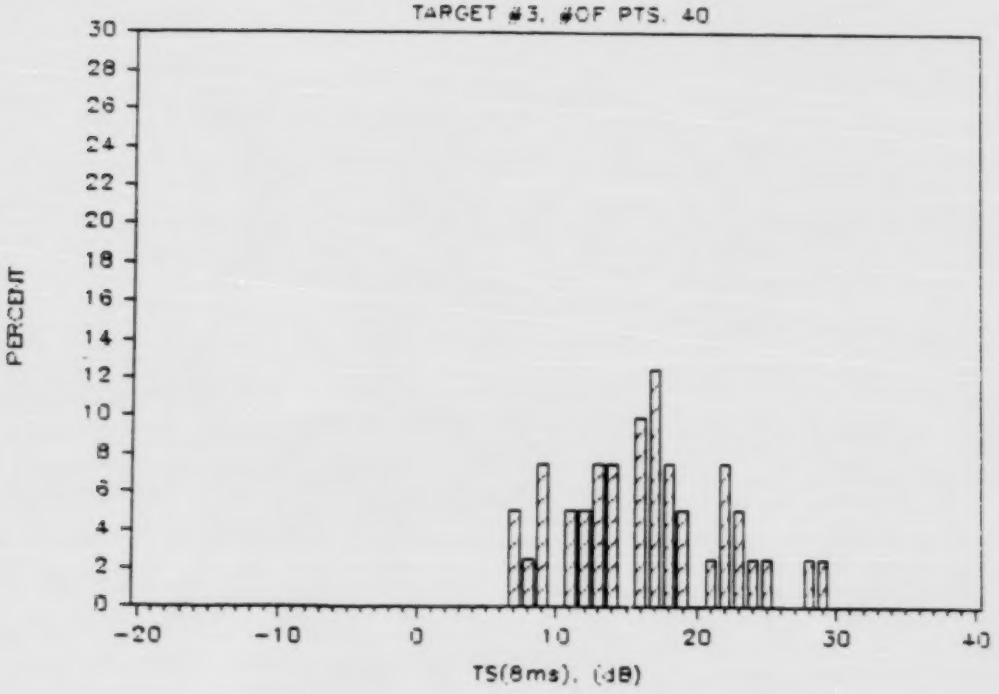
PLATE A4

Ice Cover In The Vicinity Of Iceberg #3


TARGET #3, ASPECTS 1,2,3,4
28.8
24.1
-30
TS(ENERGY), (dB)
30
20
10
0
-10
-20
-30
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
(Thousands)
RANGE, (m)


TARGET #3, #OF PTS. 40
PERCENT
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
TS(ENERGY), (dB)


TARGET #3, ASPECTS 1,2,3,4
30
20
10
0
-10
-20
-30
-40
23.7
19.6
TS(8ms), (dB)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
(Thousands)
RANGE, (m)


TARGET #3, #OF PTS. 40
PERCENT
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
TS(8ms), (dB)

DATA SUMMARY

ICEBERG NO.	: 4
POSITION	: 73 35 N, 70 49 W
TYPE	: Small Tabular
ESTIMATED DIMENSIONS	: Height above waterline: 8 m Length at waterline: 47 m Width at waterline: 38 m Estimated draught: 38 m Estimated tonnage: 39 kT
DATE	: July 8, 1986
GMT	: Start: 02:49 End: 04:53
ENVIRONMENT	: Sea State: Calm Ice Cover: 8/10 Wind Speed: 4 knots Water Depth: 1400 m Sound Speed Profile Ref: B

RUN NO.	COMMENTS
14,15,16, 20	: 8/10 ice cover, bigfloes 4/10 rubble, first year

TARGET STRENGTH MEASUREMENTS

Number of Estimates: 73
Observed at: 200-1300 m
Max. Observed Detection Range: 1300 m

	Peak Value (8ms)	Total Energy
(T.S. - sigma), dB	sigma > T.S.	sigma > T.S.
Mean Target Strength, dB	7.2	11.2
(T.S. + sigma), dB	10.4	14.5

ICEBERG #4

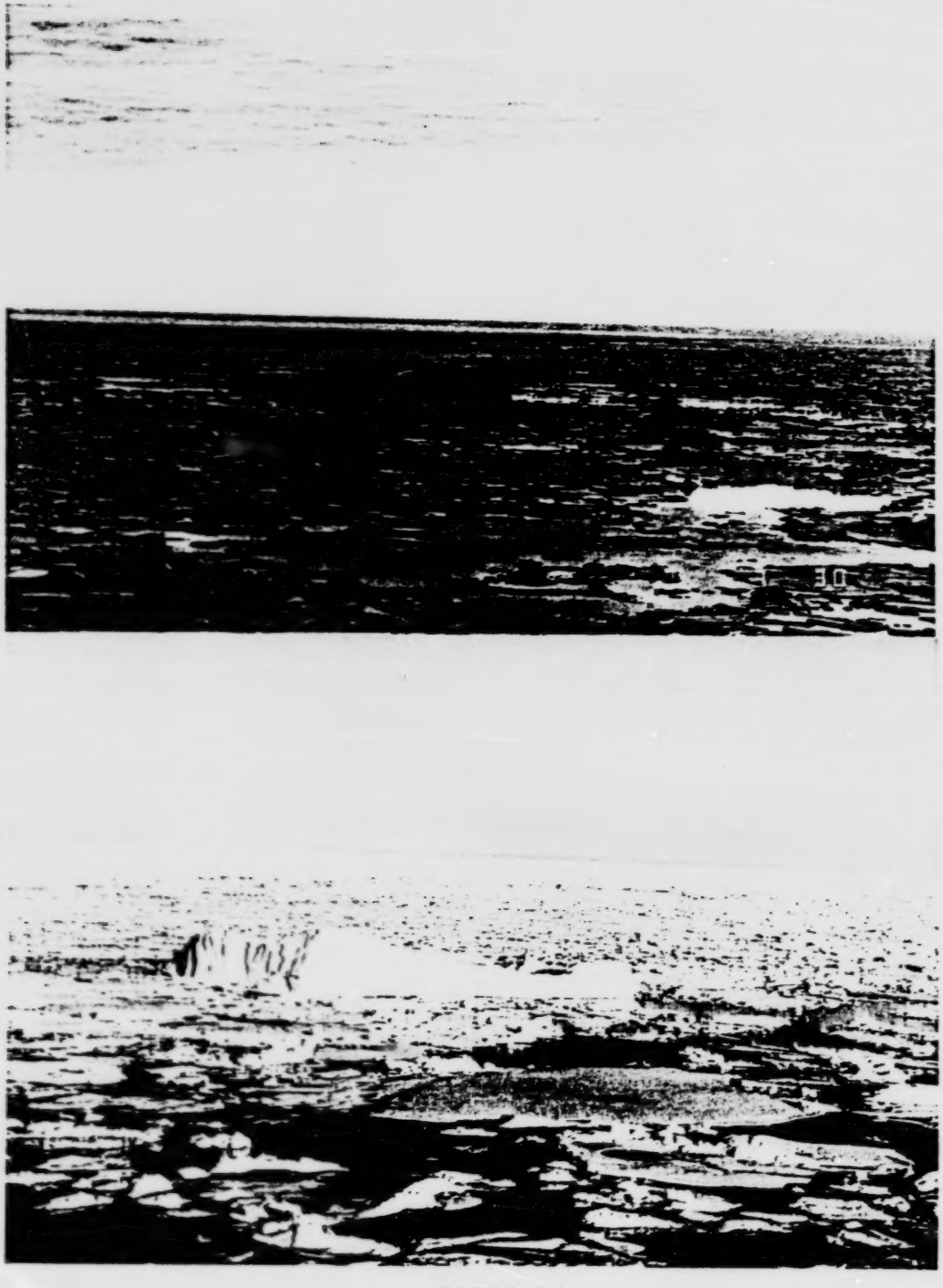


PLATE A5

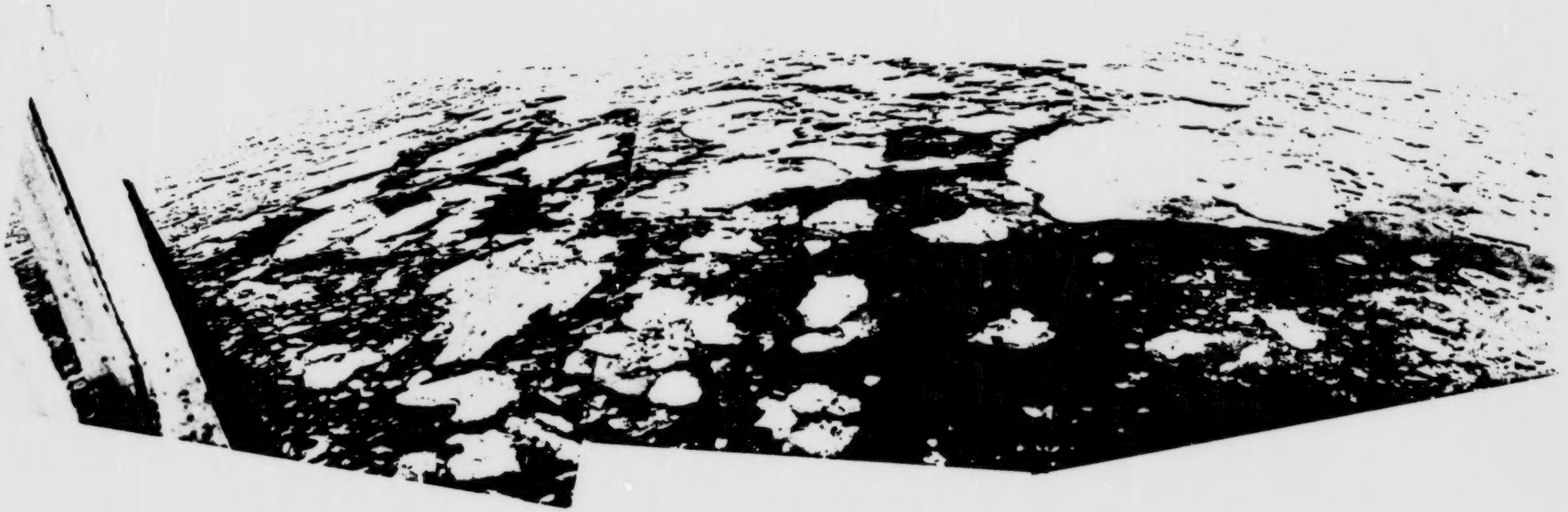
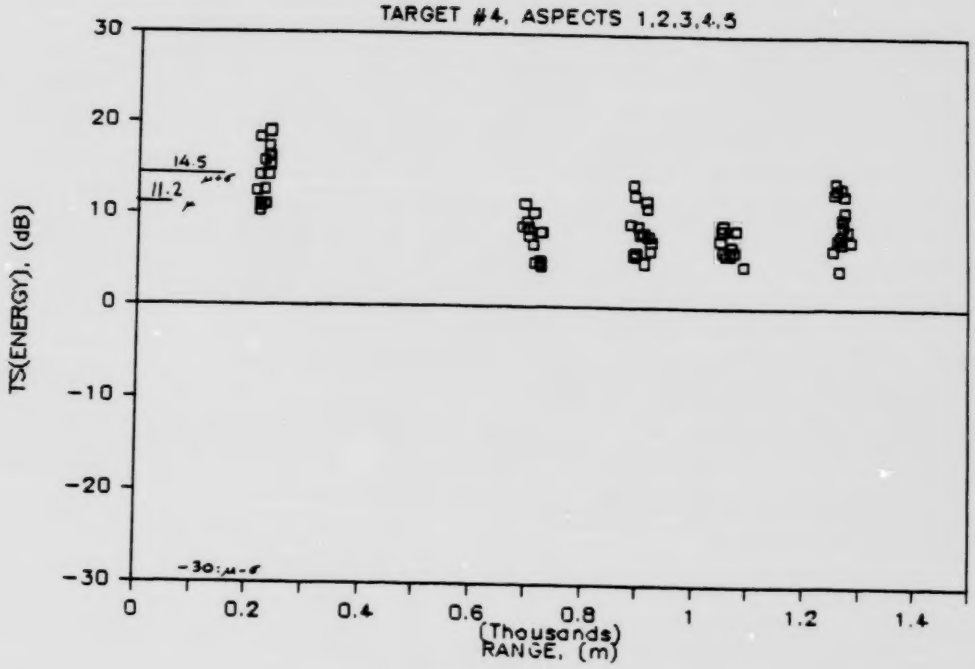
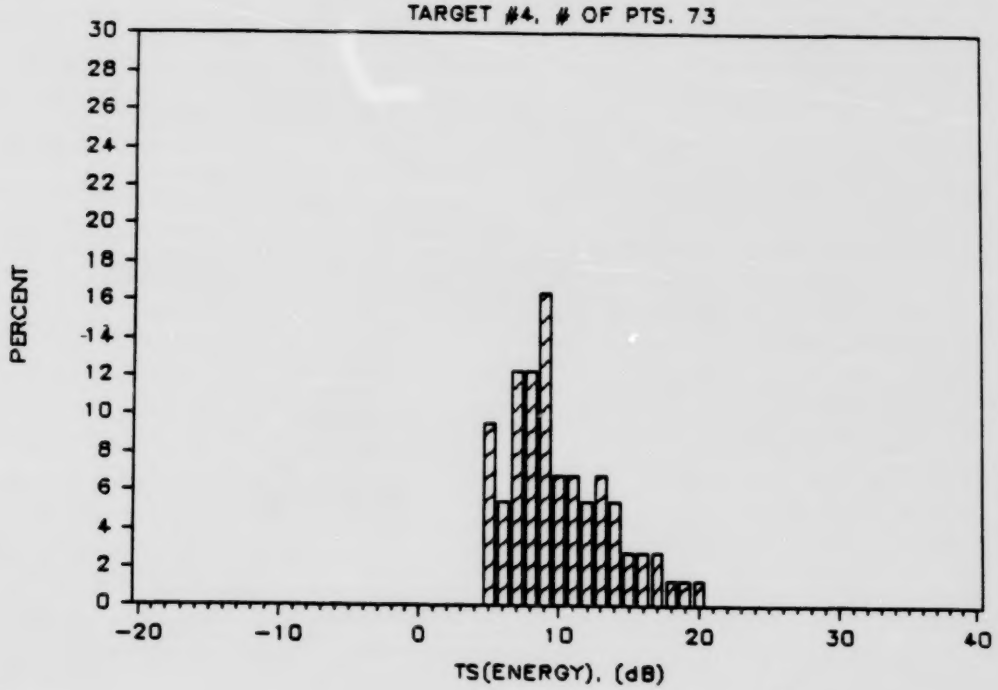
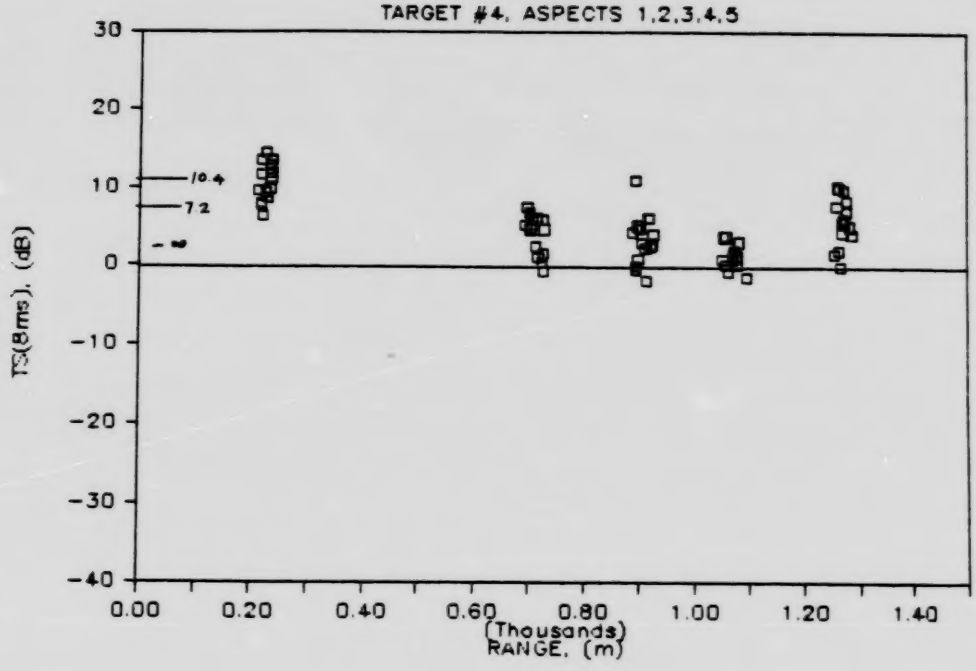


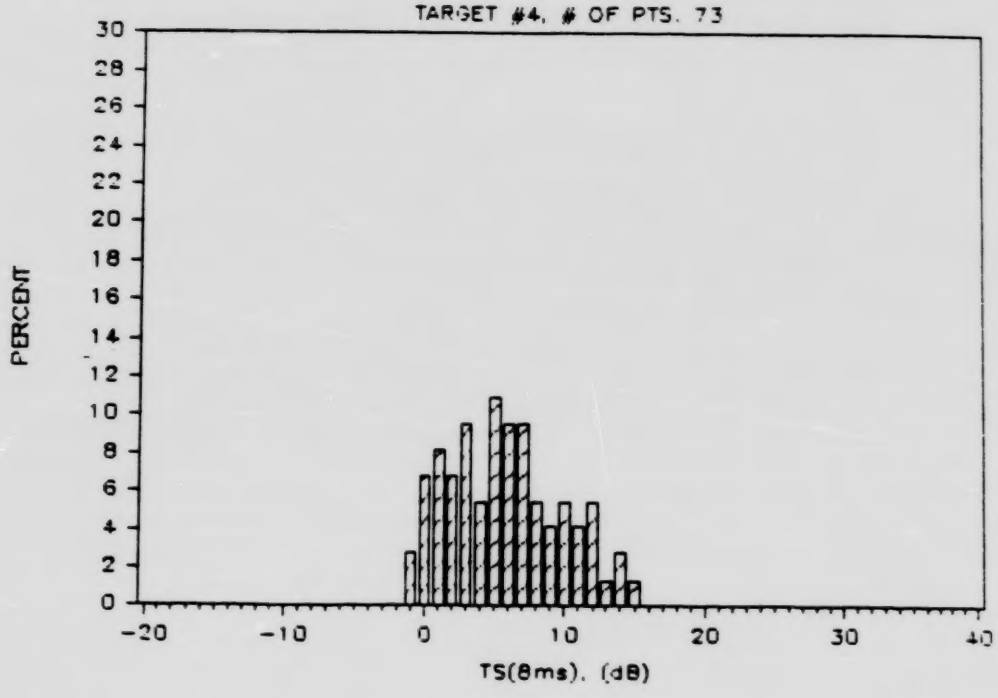
PLATE A6

Ice Cover In The Vicinity Of Iceberg #4


TARGET #4, ASPECTS 1,2,3,4,5
TS(ENERGY), (dB)
30
20
10
0
-10
-20
-30
14.5
11.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
(Thousands)
RANGE, (m)


TARGET #4, # OF PTS. 73
PERCENT
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
TS(ENERGY), (dB)


TARGET #4, ASPECTS 1,2,3,4,5
30
20
10
0
-10
-20
-30
-40
10.4
7.2
TS(8ms), (dB)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
(Thousands)
RANGE, (m)


TARGET #4, # OF PTS. 73
PERCENT
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
TS(8ms), (dB)

DATA SUMMARY

ICEBERG NO.	: 5
POSITION	: 73 35 N, 70 49 W
TYPE	: Small undefined shape
ESTIMATED DIMENSIONS	: Height above waterline: 7 m Length at waterline: 35 m Width at waterline: 15 m Estimated draught: 18 m Estimated tonnage: 11 kT
DATE	: July 8, 1986
GMT	: Start: 04:02 End: 05:01
ENVIRONMENT	: Sea State: N/A Ice Cover: 8/10 Wind Speed: 4 knots Water Depth: 1400 m Sound Speed Profile Ref: B

RUN NO.	COMMENTS
17,18,21	: 8/10 ice cover, bigfloes, 4/10 rubble, first year

TARGET STRENGTH MEASUREMENTS

Number of Estimates: 42
Observed at: 200-400 m
Max. Observed Detection Range: 400 m

	Peak Value (8ms)	Total Energy
(T.S. - sigma), dB	sigma > T.S.	sigma > T.S.
Mean Target Strength, dB	-5.3	-3.1
(T.S. + sigma), dB	-2.1	0.6

ICEBERG #5

PLATE A7

ICE COVER IN THE VICINITY OF ICEBERG #5

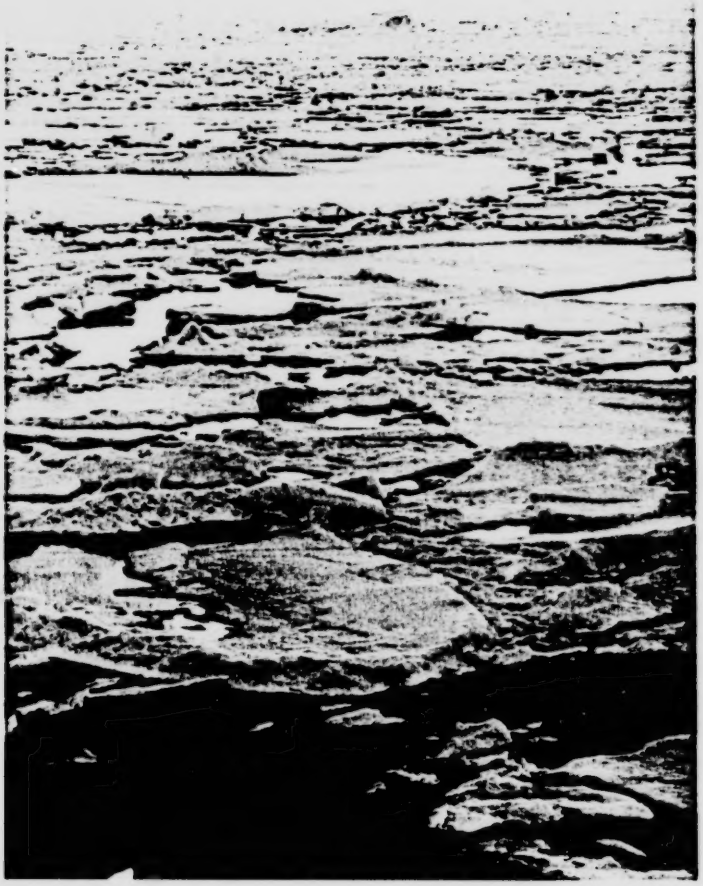
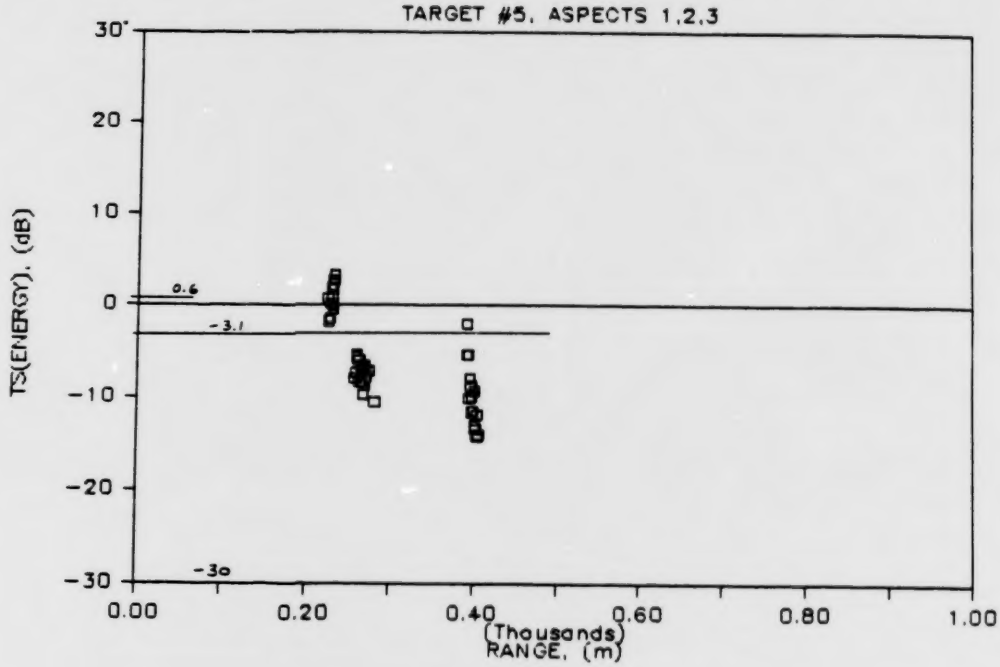
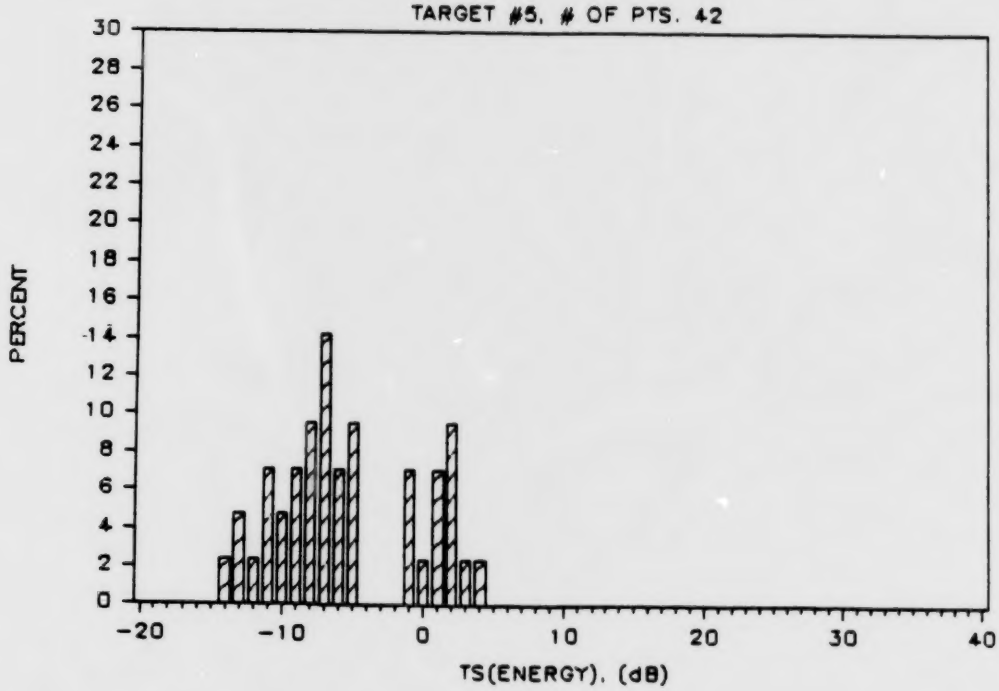
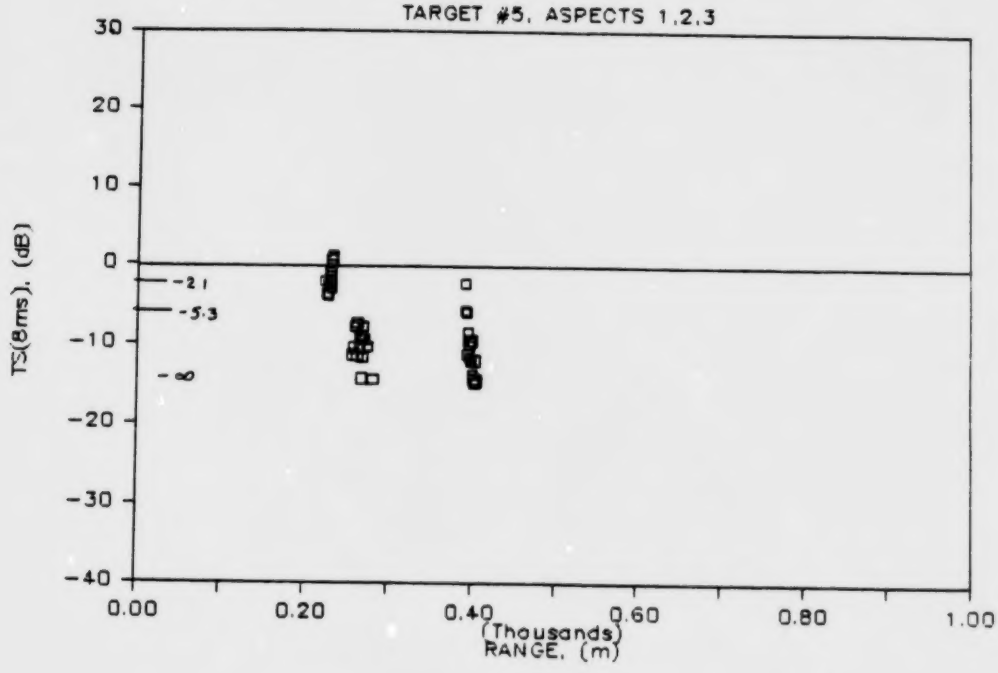
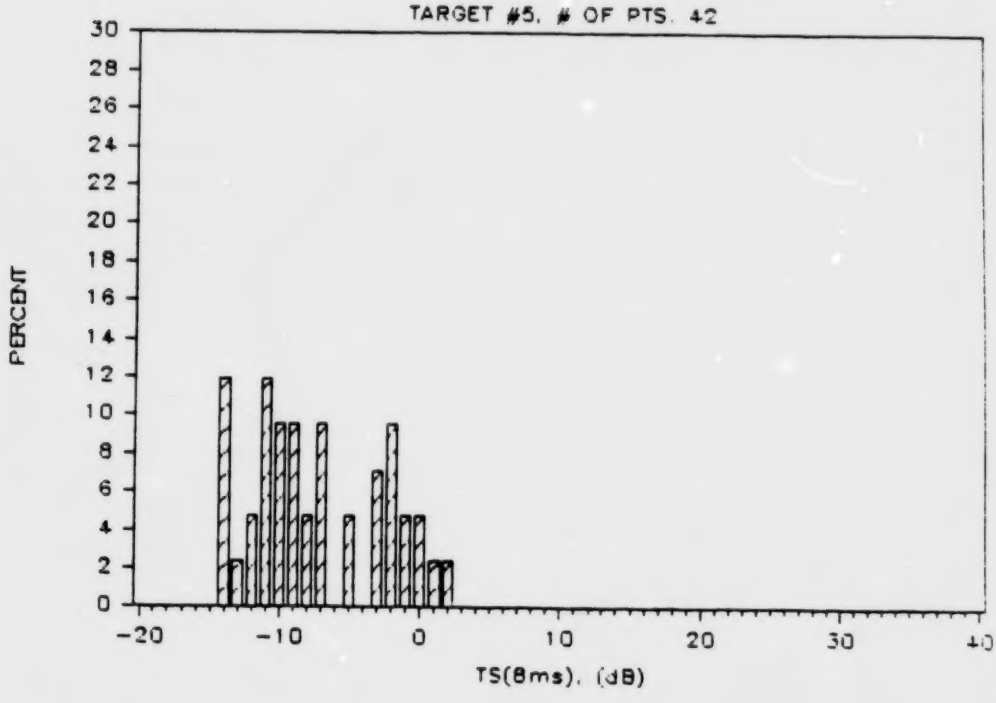


PLATE A8


TARGET #5, ASPECTS 1,2,3
30
20
10
0
-10
-20
-30
TS(ENERGY), (dB)
0.6
-3.1
-30
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE, (m)


TARGET #5, # OF PTS. 42
PERCENT
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
TS(ENERGY), (dB)


TARGET #5, ASPECTS 1,2,3
30
20
10
0
-10
-20
-30
-40
TS(8ms), (dB)
-2.1
-5.3
-∞
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE, (m)


TARGET #5, # OF PTS. 42
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
PERCENT
-20
-10
0
10
20
30
40
TS(8ms), (dB)

DATA SUMMARY

ICEBERG NO.	: 6
POSITION	: 73 10 N, 64 39 W
TYPE	: Medium Picturesque
ESTIMATED DIMENSIONS	: Height above waterline: 16 m Length at waterline: 116 m Width at waterline: 116 m Estimated draught: 56 m Estimated tonnage: 648 kT
DATE	: July 8,9, 1986
GMT	: Start: 22:55 End: 07:00
ENVIRONMENT	: Sea State: Calm, fog Ice Cover: 10/10 Wind Speed: 8 knots Water Depth: 2200 m Sound Speed Profile Ref: C & D

RUN NO.	COMMENTS
23,24, 29-33	: First year ice, big floes, level

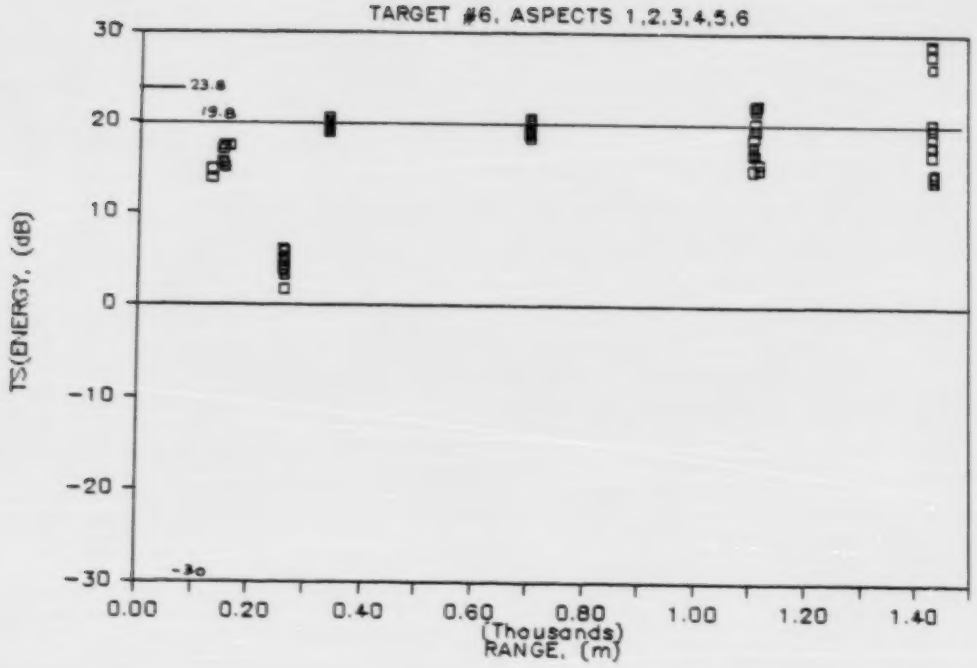
TARGET STRENGTH MEASUREMENTS

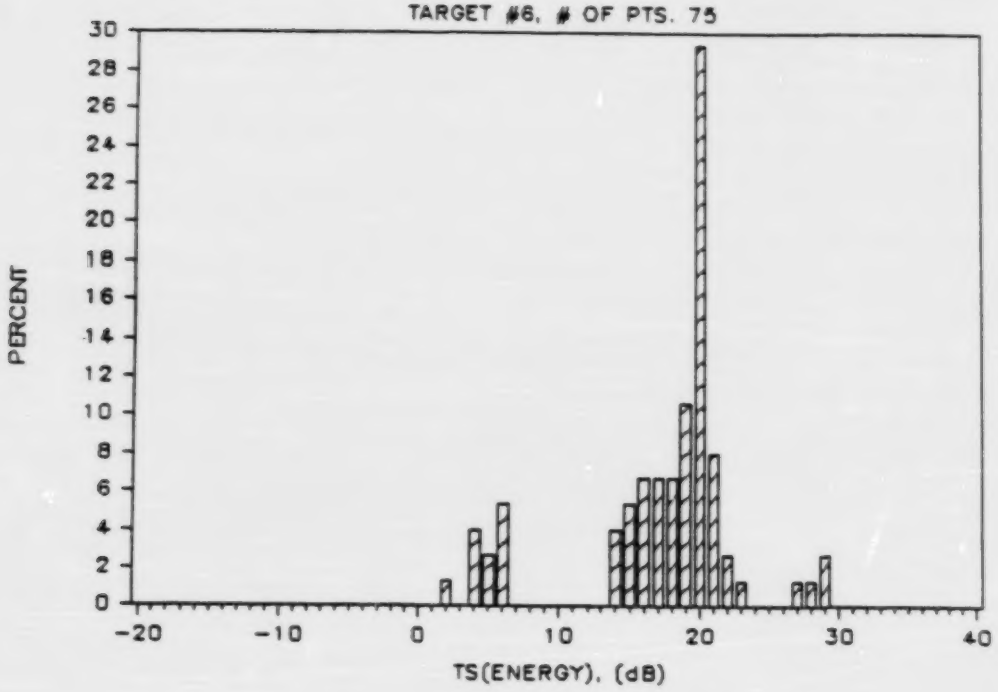
Number of Estimates: 75
Observed at: 150-1450 m
Max. Observed Detection Range: 1850 m

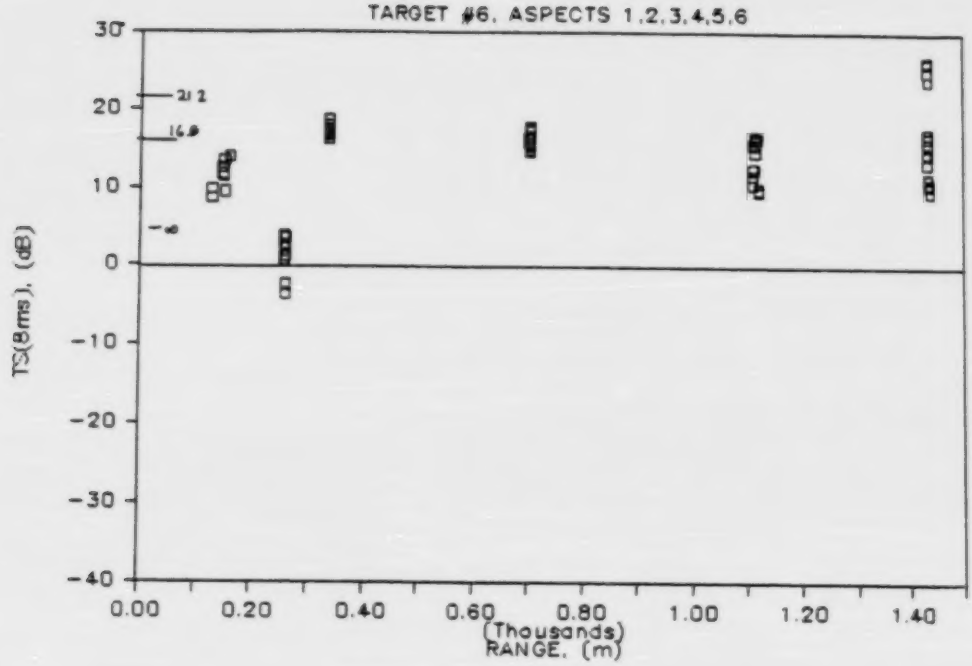
	Peak Value (8ms)	Total Energy
(T.S. - sigma), dB	sigma > T.S.	sigma > T.S.
Mean Target Strength, dB	16.9	19.8
(T.S. + sigma), dB	21.2	23.8

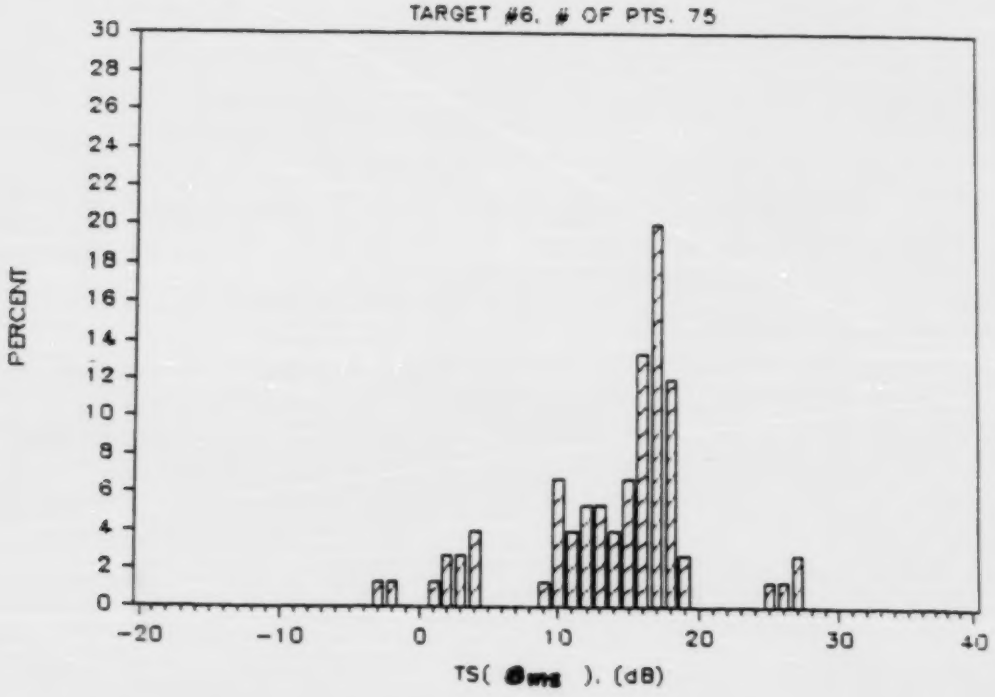
ICEBERG #6

PLATE A9


TARGET #6, ASPECTS 1,2,3,4,5,6
30
20
10
0
-10
-20
-30
23.8
19.8
-30
TS(ENERGY), (dB)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
(Thousands)
RANGE, (m)


TARGET #6, # OF PTS. 75
PERCENT
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
TS(ENERGY), (dB)


TARGET #6, ASPECTS 1,2,3,4,5,6
TS(8ms), (dB)
30
20
10
0
-10
-20
-30
-40
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
(Thousands)
RANGE, (m)


TARGET #6, # OF PTS. 75
PERCENT
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
TS(8ms), (dB)

DATA SUMMARY

PROPAGATION EXPERIMENTS

POSITION : 73 10 N, 64 39 W

DATE : July 9, 1986

GMT : Start: 16:16
End: 17:57

ENVIRONMENT : Sea State: Calm, fog
Ice Cover: 10/10
Wind Speed: 8 knots
Water Depth: 2200 m

RUN NO.	COMMENTS
35-46	: First year ice, big floes, level

ICE COVER IN VICINITY OF SOUND PROPAGATION EXPERIMENT

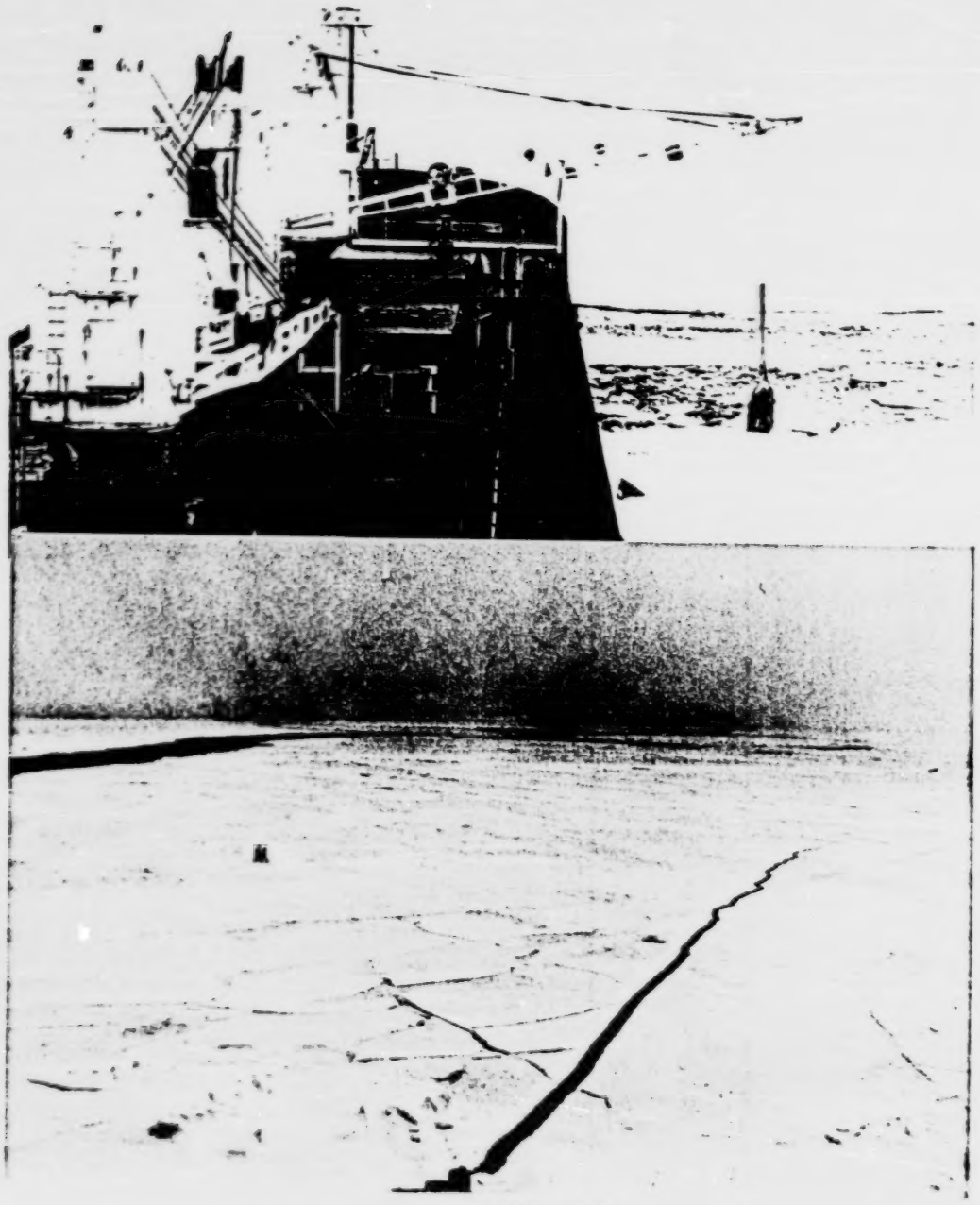


PLATE A10

DATA SUMMARY

ICEBERG NO. : 7

POSITION : 72 56 N, 60 21 W

TYPE : Small domed

ESTIMATED DIMENSIONS :
Height above waterline: 8 m
Length at waterline: 39 m
Width at waterline: 39 m
Estimated draught: 31 m
Estimated tonnage: 35 kT

DATE : July 9, 1986

GMT :
Start: 19:20
End: 22:38

ENVIRONMENT :
Sea State: N/A
Ice Cover: 10/10
Wind Speed: 2 knots
Water Depth: 400 m
Sound Speed
Profile Ref: X

RUN NO.	COMMENTS
48-51	Thick first year ice, (120 cm)

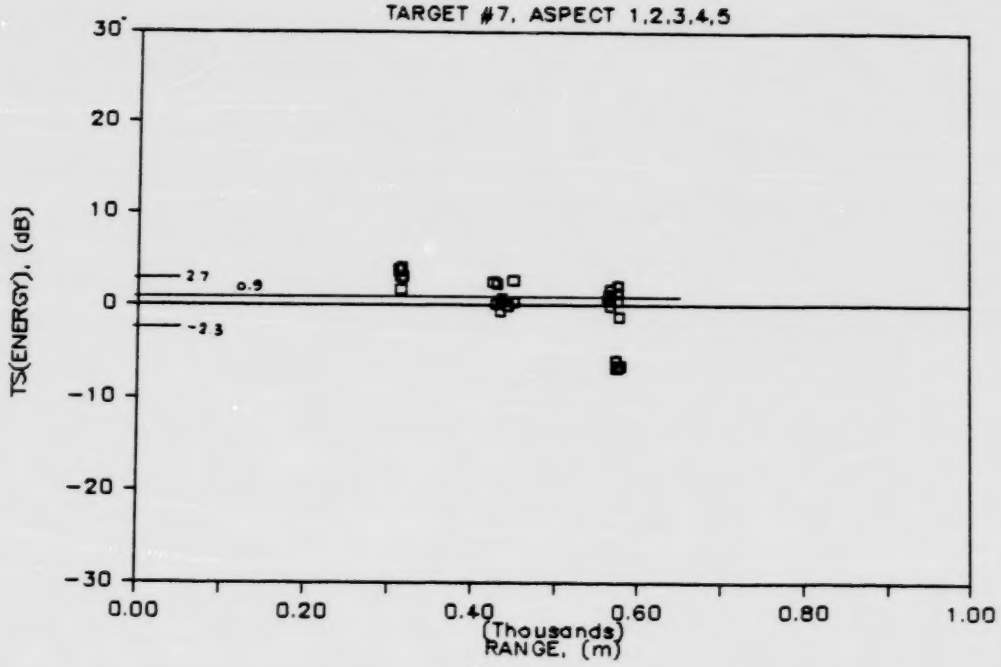
TARGET STRENGTH MEASUREMENTS

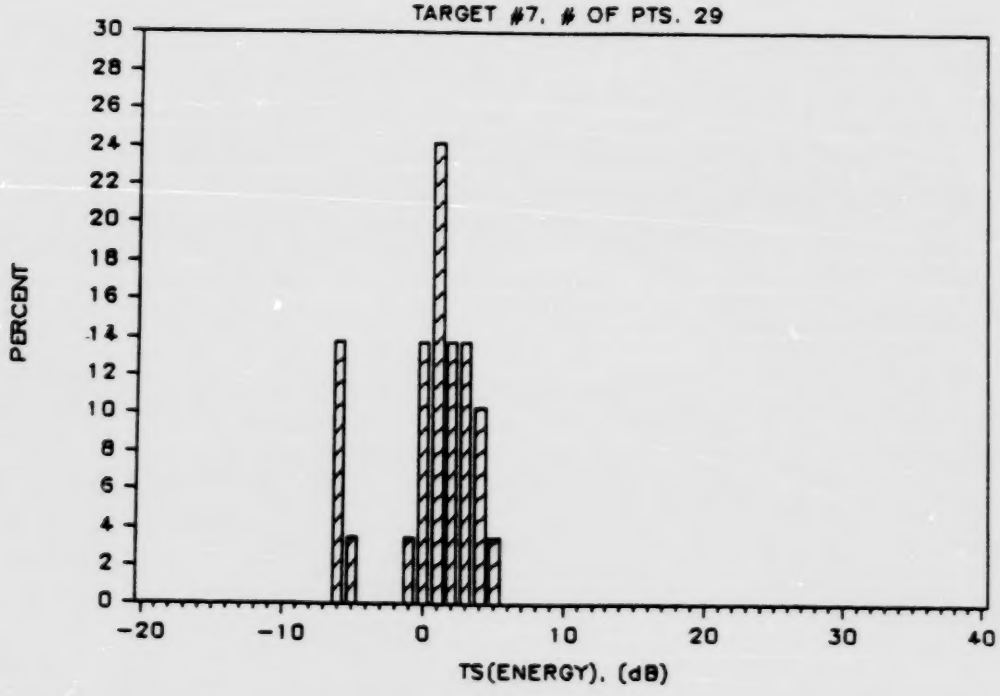
Number of Estimates: 29
Observed at: 200-600 m
Max. Observed Detection Range: 600 m

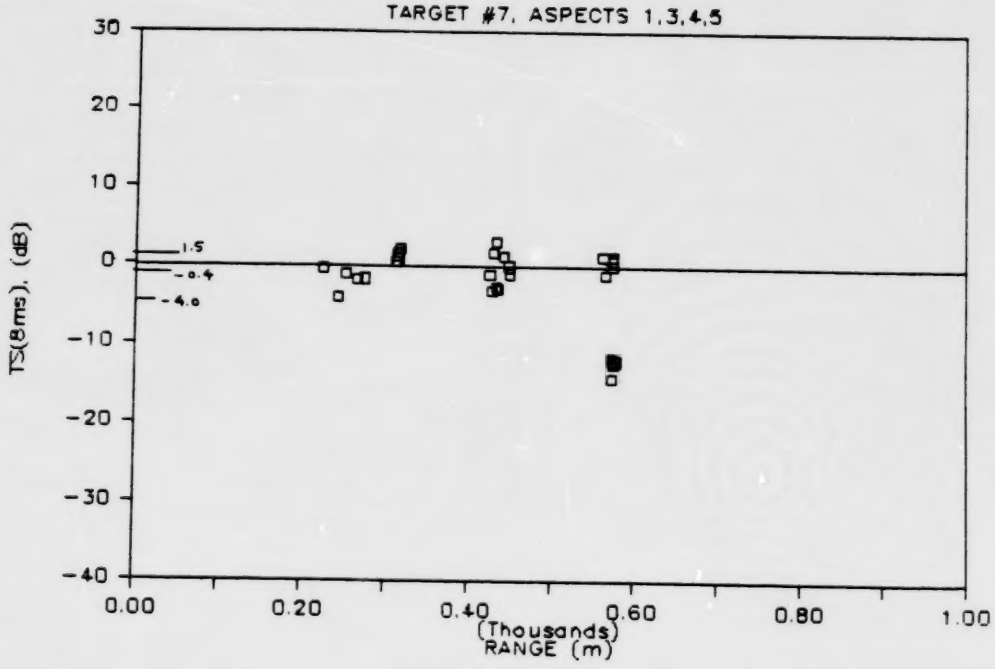
	Peak Value (8ms)	Total Energy
(T.S. - sigma), dB	-4.0	-2.3
Mean Target Strength, dB	-0.4	0.9
(T.S. + sigma), dB	1.5	2.7

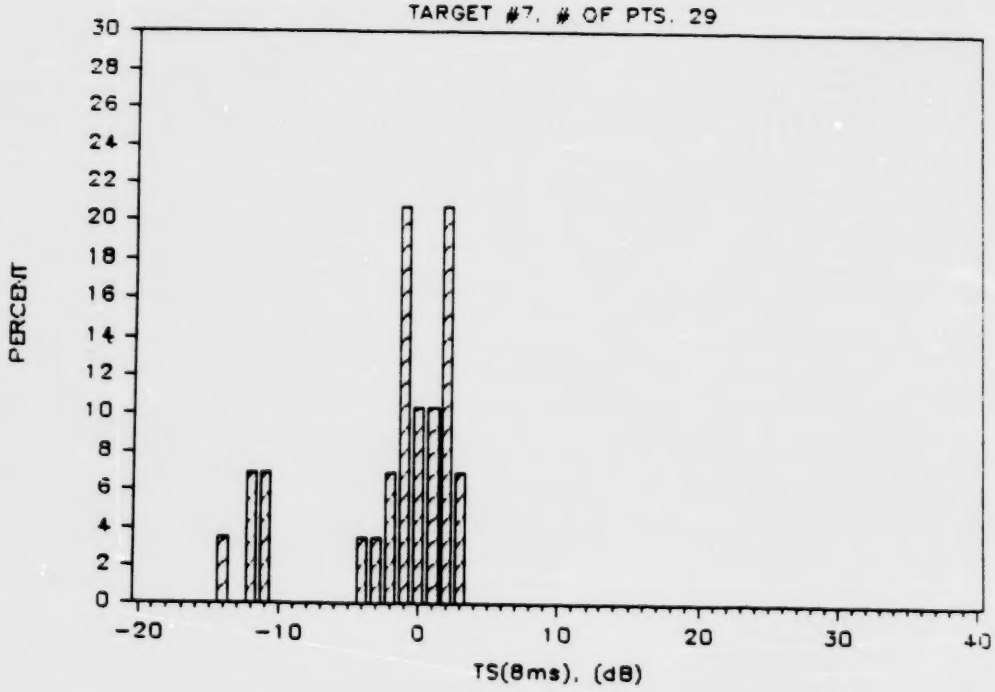
ICEBERG #7
(not visible in fog)

PLATE A11


TARGET #7, ASPECT 1,2,3,4,5
30
20
10
0
-10
-20
-30
TS(ENERGY), (dB)
2.7
0.9
-2.3
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE, (m)


TARGET #7, # OF PTS. 29
PERCENT
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
TS(ENERGY), (dB)


TARGET #7, ASPECTS 1,3,4,5
TS(8ms), (dB)
30
20
10
0
-10
-20
-30
-40
1.5
-0.4
-4.0
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE (m)


TARGET #7, # OF PTS. 29
PERCENT
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
TS(8ms), (dB)

DATA SUMMARY

ICEBERG NO.	: 8
POSITION	: 72 38 N, 58 33 W
TYPE	: Weathered small berg
ESTIMATED DIMENSIONS	: Height above waterline: 13 m Length at waterline: 31 m Width at waterline: 25 m Estimated draught: 24 m Estimated tonnage: 29 kT
DATE	: July 10, 1986
GMT	: Start: 06:55 End: 07:33
ENVIRONMENT	: Sea State: Low sea state Ice Cover: 1/10 Wind Speed: 7 knots Water Depth: 100-250 m Sound Speed Profile Ref: E

RUN NO.	COMMENTS
53-55	: 1/10 ice cover, (40 cm sea ice)

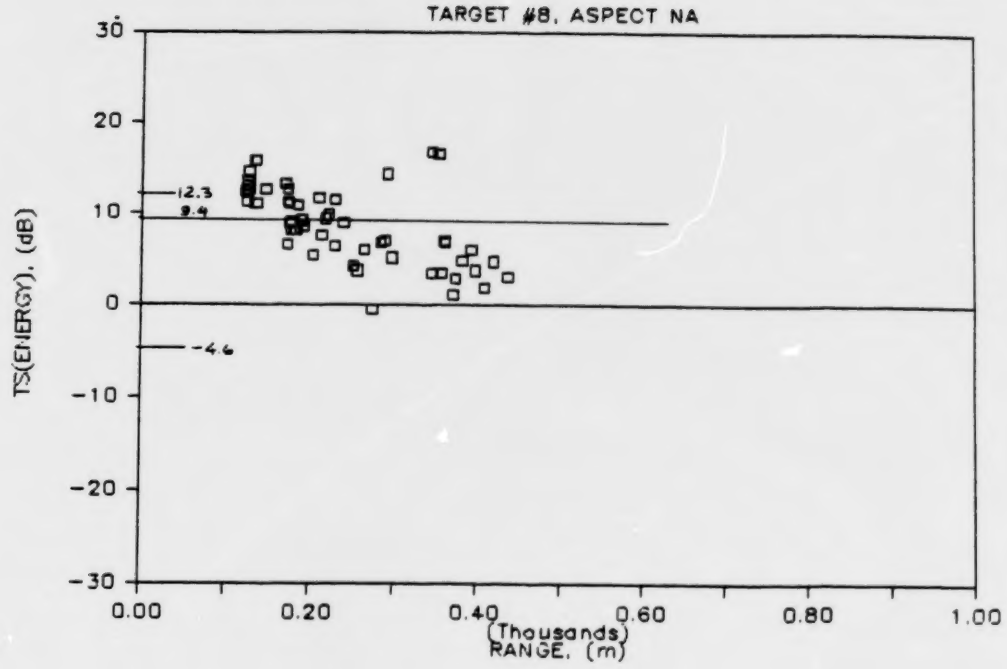
TARGET STRENGTH MEASUREMENTS

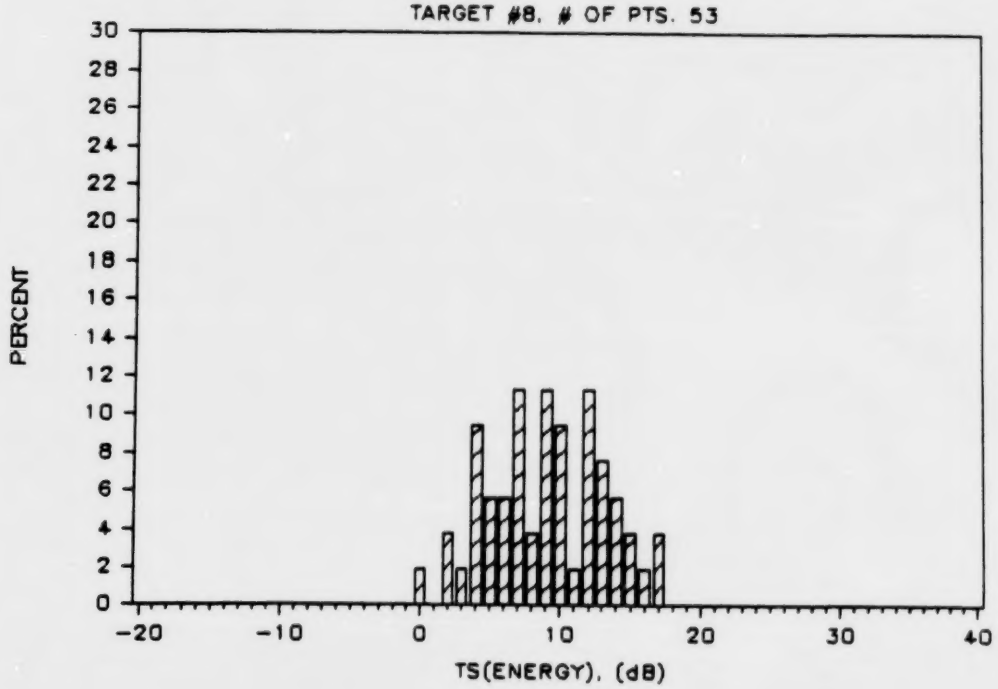
Number of Estimates: 53
Observed at: 100-450 m
Max. Observed Detection Range: 450 m

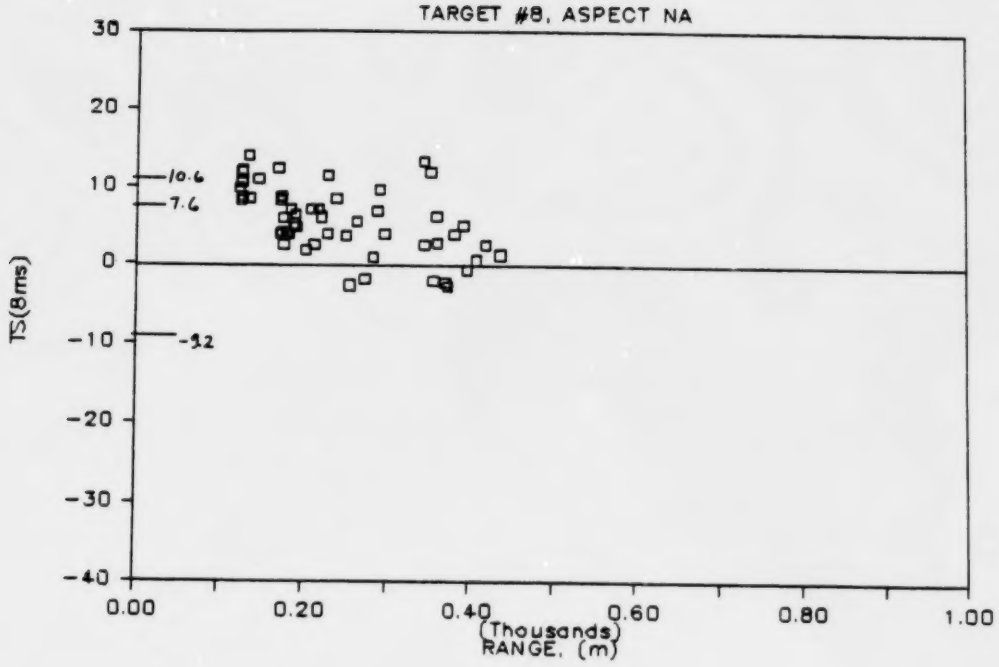
	Peak Value (8ms)	Total Energy
(T.S. - sigma), dB	-9.2	-4.6
Mean Target Strength, dB	7.6	9.4
(T.S. + sigma), dB	10.6	12.3

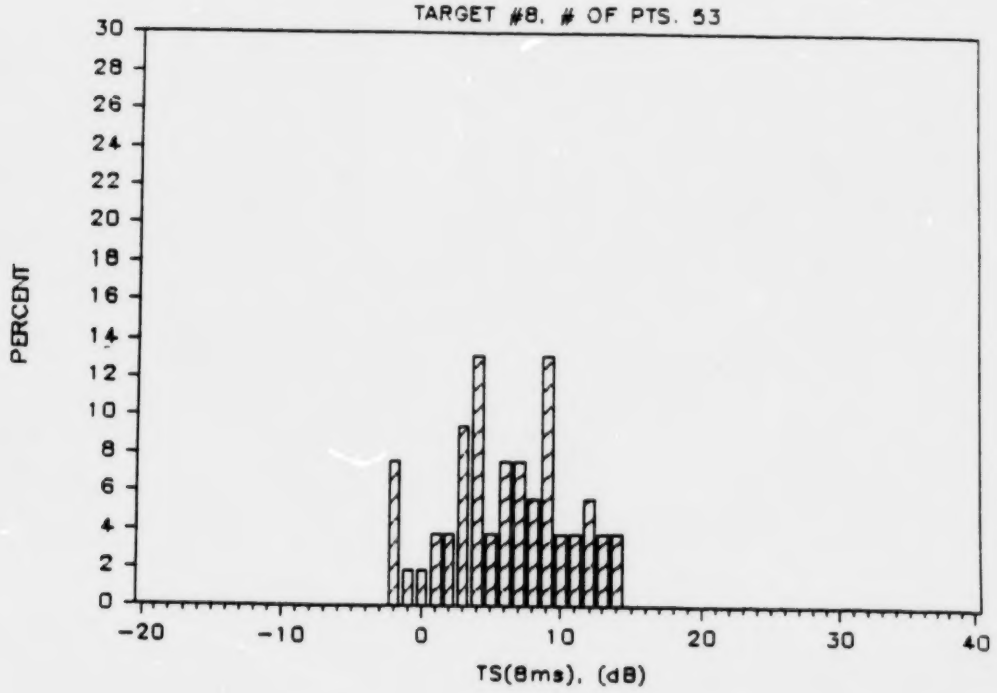
ICEBERG #8

PLATE A12


TARGET #8, ASPECT NA
30
20
10
0
-10
-20
-30
12.3
9.4
-4.4
TS(ENERGY), (dB)
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE, (m)


TARGET #8, # OF PTS. 53
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
PERCENT
-20
-10
0
10
20
30
40
TS(ENERGY), (dB)


TARGET #8, ASPECT NA
30
20
10
0
-10
-20
-30
-40
10.6
7.6
-3.2
TS(8ms)
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE, (m)


TARGET #8, # OF PTS. 53
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
PERCENT
-20
-10
0
10
20
30
40
TS(8ms), (dB)

DATA SUMMARY

ICEBERG NO.	: 9
POSITION	: 72 30 N, 58 18 W
TYPE	: Large Blocky
ESTIMATED DIMENSIONS	: Height above waterline: 17 m Length at waterline: 136 m Width at waterline: 136 m Estimated draught: 125 m Estimated tonnage: 1.4 MT
DATE	: July 10, 1986
GMT	: Start: 09:55 End: 10:58
ENVIRONMENT	: Sea State: Calm Ice Cover: < 1/10 Wind Speed: 12 knots Water Depth: 100-250 m Sound Speed Profile Ref: E

RUN NO.	COMMENTS
56,57	: Open water, (< 1/10 ice cover)

TARGET STRENGTH MEASUREMENTS

Number of Estimates: 106
Observed at: 100-650 m
Max. Observed Detection Range: 850 m, (lost in bottom echo)

	Peak Value (8ms)	Total Energy
(T.S. - sigma), dB	sigma > T.S.	sigma > T.S.
Mean Target Strength, dB	20.3	23.8
(T.S. + sigma), dB	24.3	27.0

ICEBERG #9

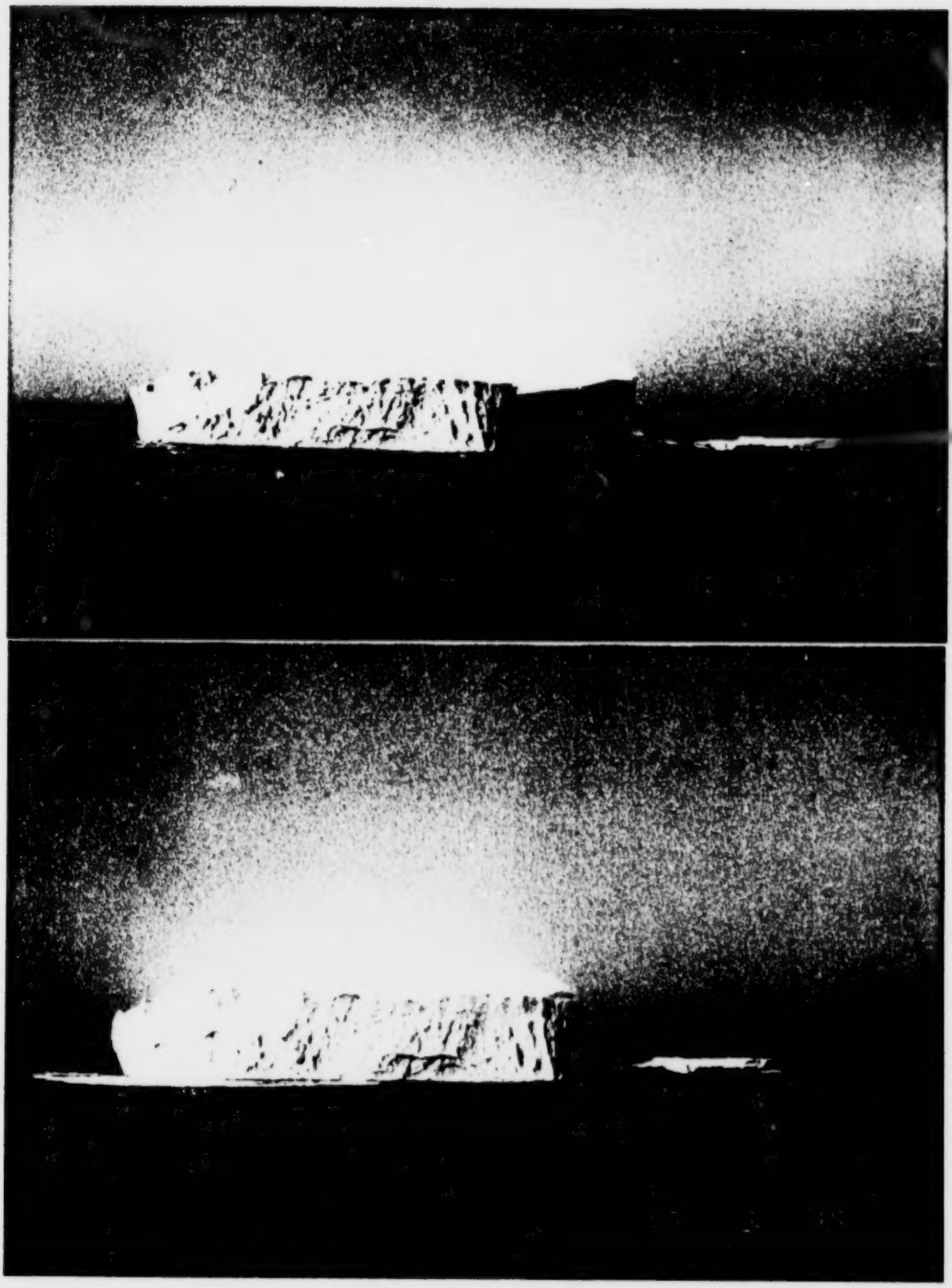
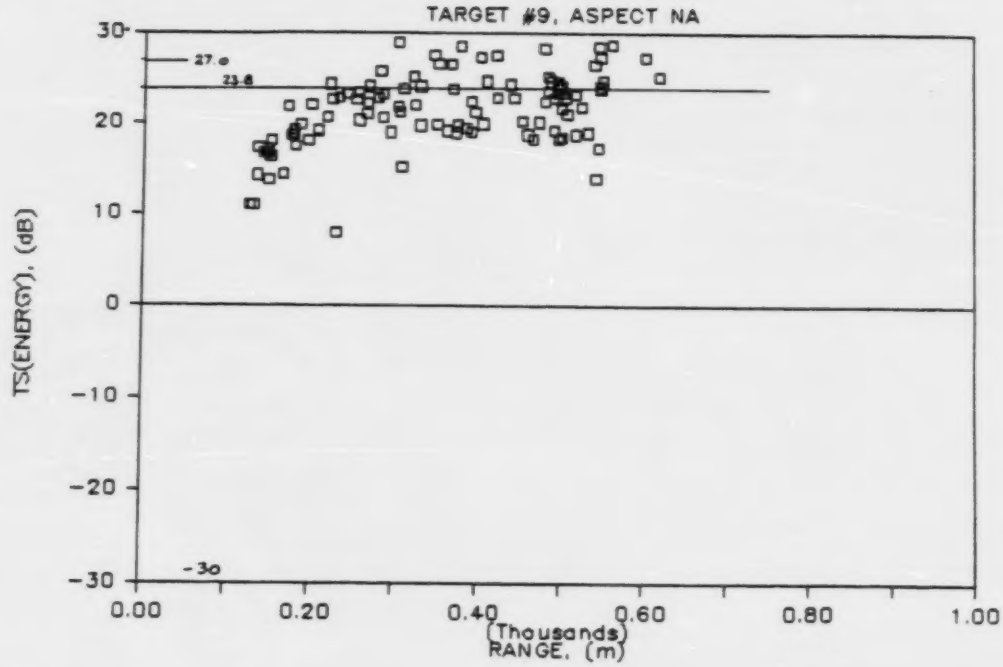
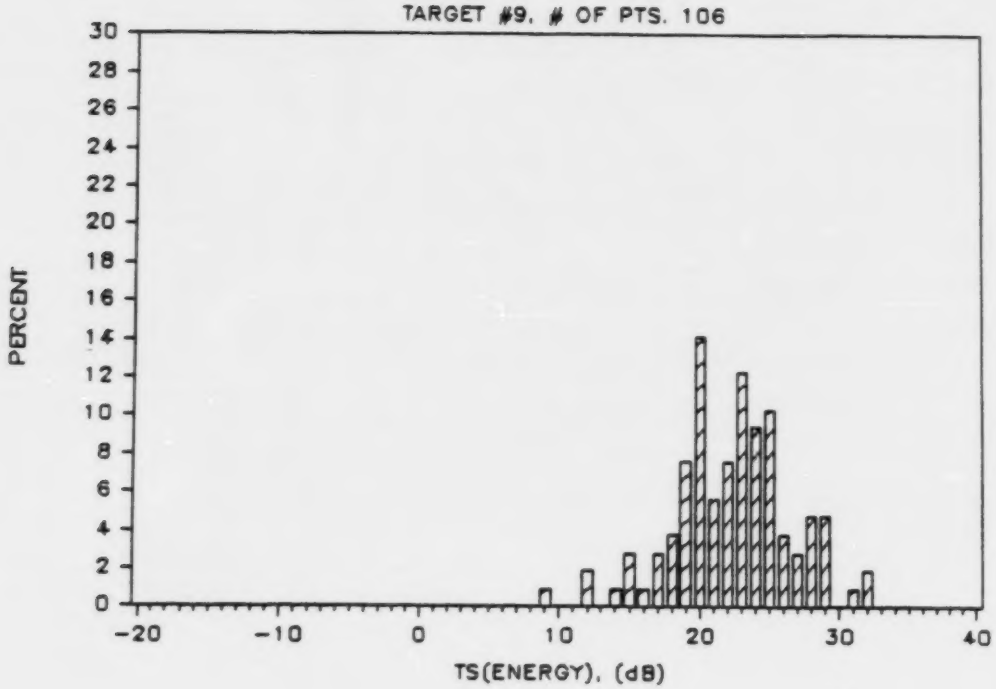
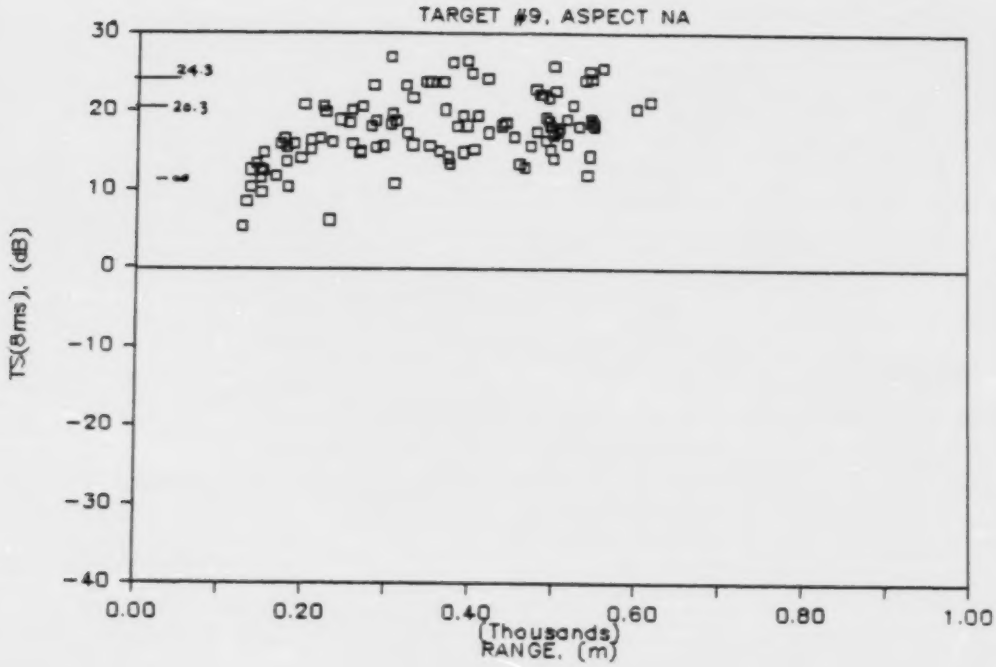
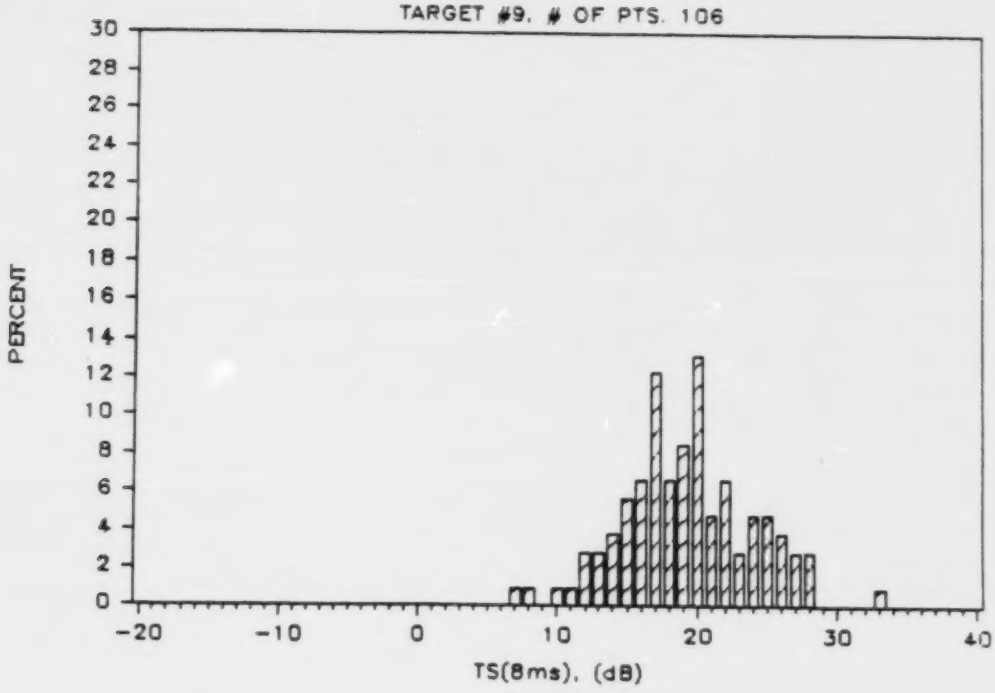


PLATE A13


TARGET #9, ASPECT NA
30
27.0
23.8
20
10
0
-10
-20
-30
-30
TS(ENERGY), (dB)
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE, (m)


TARGET #9, # OF PTS. 106
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
PERCENT
-20
-10
0
10
20
30
40
TS(ENERGY), (dB)


TARGET #9, ASPECT NA
24.3
26.3
30
20
10
0
-10
-20
-30
-40
TS(8ms), (dB)
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE, (m)


TARGET #9, # OF PTS. 106
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
PERCENT
-20
-10
0
10
20
30
40
TS(8ms), (dB)

DATA SUMMARY

ICEBERG NO.	: 10
POSITION	: 72 30 N, 58 18 W
TYPE	: Bergy Bit
ESTIMATED DIMENSIONS	: Height above waterline: 2 m Length at waterline: 17 m Width at waterline: 17 m Estimated draught: 7 m Estimated tonnage: 368 T
DATE	: July 10, 1986
GMT	: Start: 11:29 End: 11:34
ENVIRONMENT	: Sea State: Calm Ice Cover: < 1/10 Wind Speed: 12 knots Water Depth: 100-250 m Sound Speed Profile Ref: E

RUN NO.	COMMENTS
58	: Open water, (< 1/10 ice cover)

TARGET STRENGTH MEASUREMENTS

Number of Estimates: 13
Observed at: 100-200 m
Max. Observed Detection Range: 200 m

	Peak Value (8ms)	Total Energy
(T.S. - sigma), dB	-17.8	-14.9
Mean Target Strength, dB	-11.1	-9.3
(T.S. + sigma), dB	-8.6	-6.9

ICEBERG #10

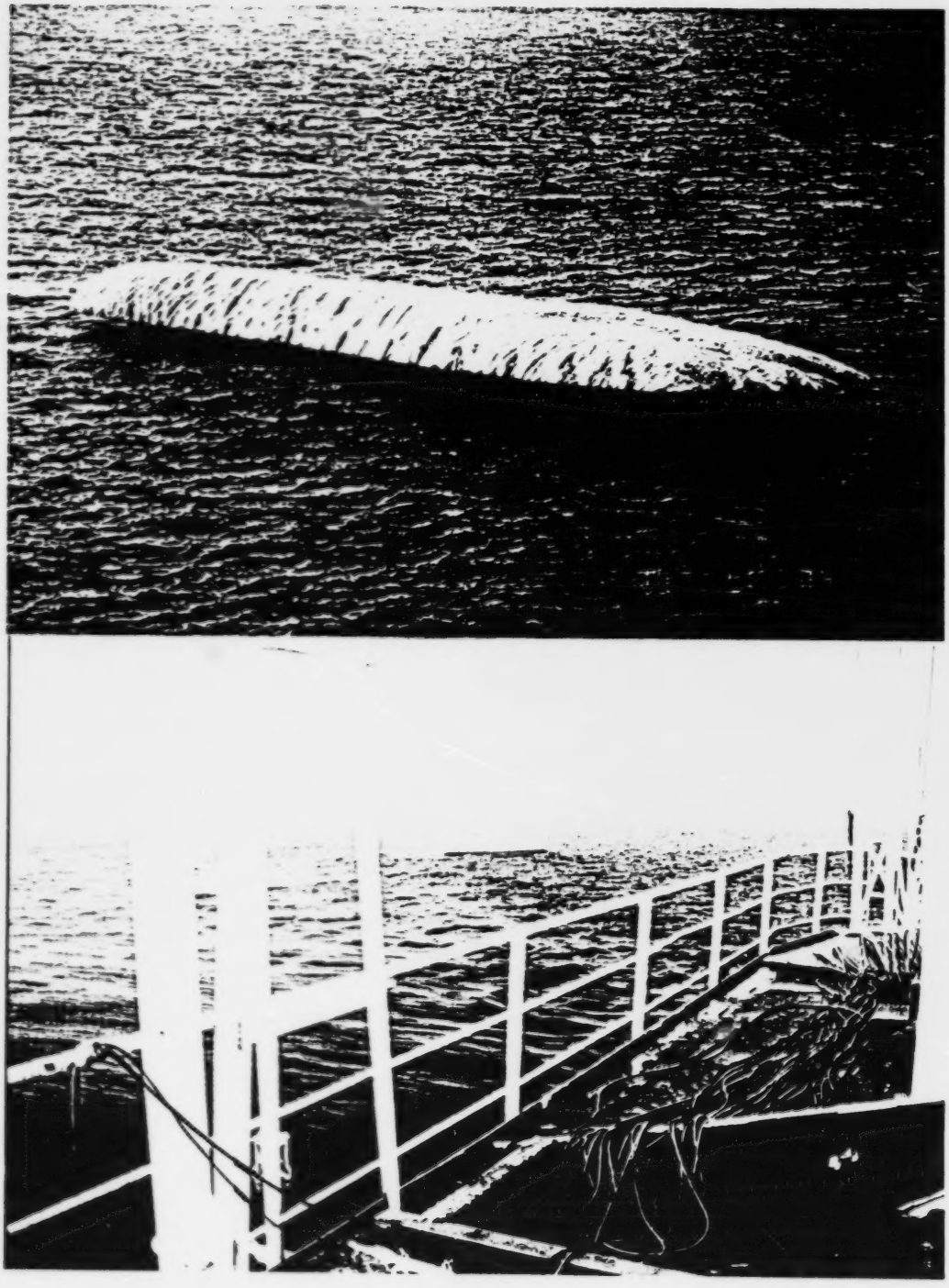
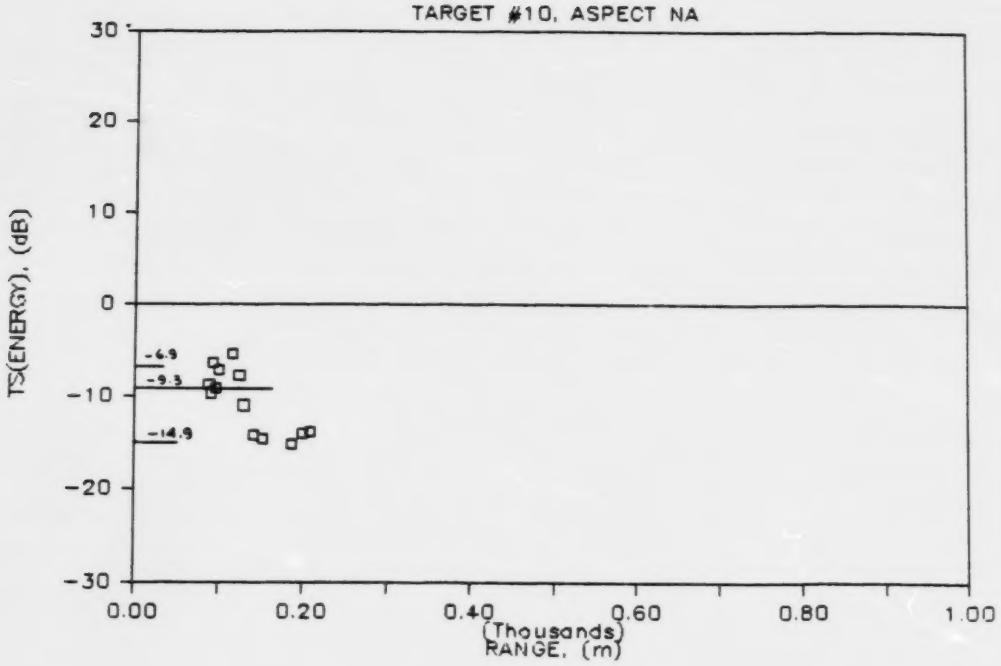
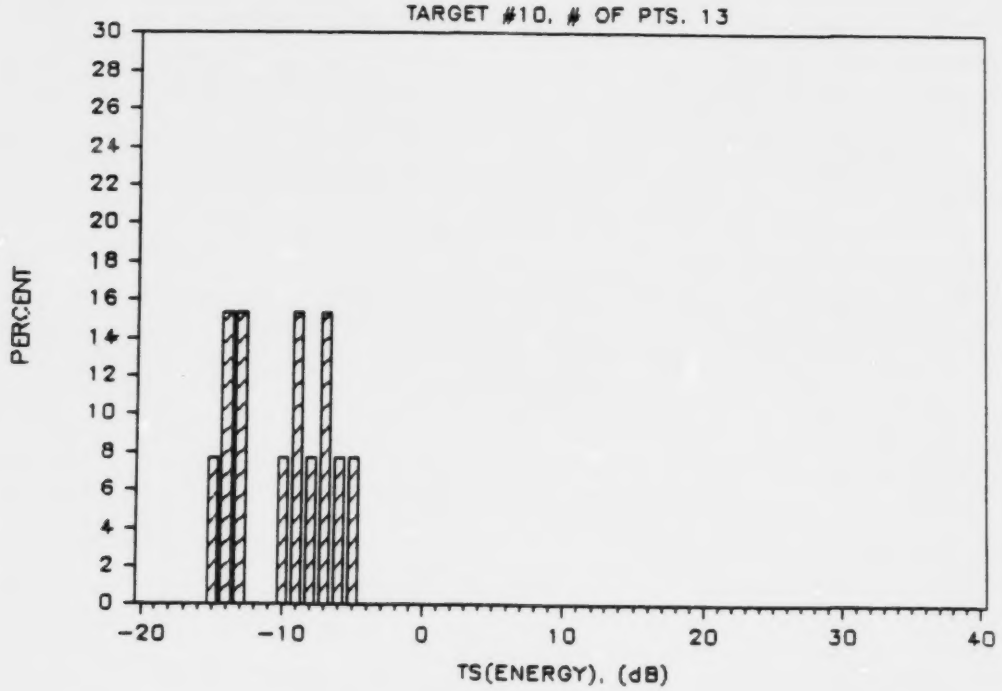
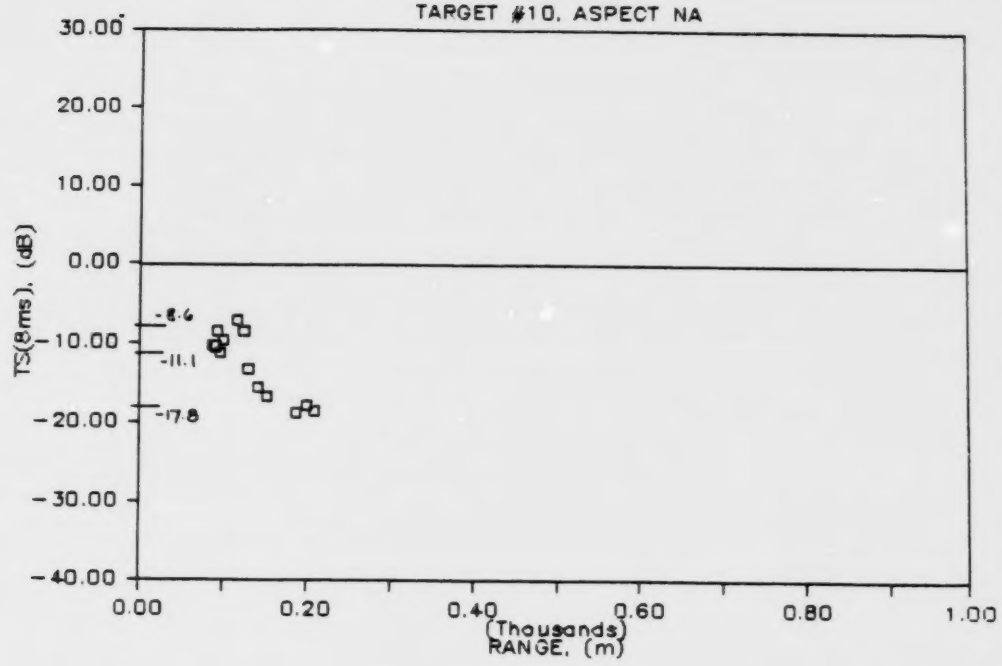
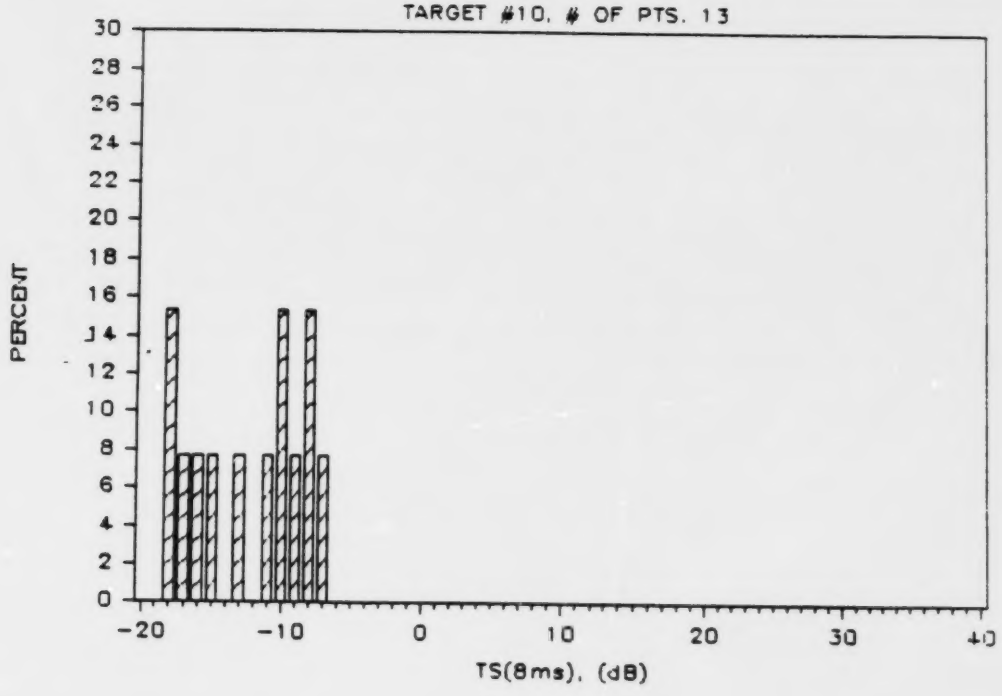


PLATE A14


TARGET #10, ASPECT NA
TS(ENERGY), (dB)
30
20
10
0
-10
-20
-30
-6.9
-9.3
-14.9
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE, (m)


TARGET #10, # OF PTS. 13
PERCENT
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
TS(ENERGY), (dB)


TARGET #10, ASPECT NA
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
TS(8ms), (dB)
-8.6
-11.1
-17.8
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE, (m)


TARGET #10, # OF PTS. 13
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
PERCENT
-20
-10
0
10
20
30
40
TS(8ms), (dB)

DATA SUMMARY

ICEBERG NO.	: 11
POSITION	: 72 30 N, 58 18 W
TYPE	: Medium Picturesque
ESTIMATED DIMENSIONS	: Height above waterline: 20 m Length at waterline: 55 m Width at waterline: 55 m Estimated draught: 50 m Estimated tonnage: 182 kT
DATE	: July 10, 1986
GMT	: Start: 11:59 End: 12:42
ENVIRONMENT	: Sea State: Calm Ice Cover: < 1/10 Wind Speed: 12 knots Water Depth: 100-250 m Sound Speed Profile Ref: E

RUN NO.	COMMENTS
59,60	: Open water, (< 1/10 ice cover)

TARGET STRENGTH MEASUREMENTS

Number of Estimates: 96
Observed at: 200-600 m
Max. Observed Detection Range: 600 m

	Peak Value (8ms)	Total Energy
(T.S. - sigma), dB	sigma > T.S.	sigma > T.S.
Mean Target Strength, dB	15.5	17.1
(T.S. + sigma), dB	18.6	20.0

ICEBERG #11

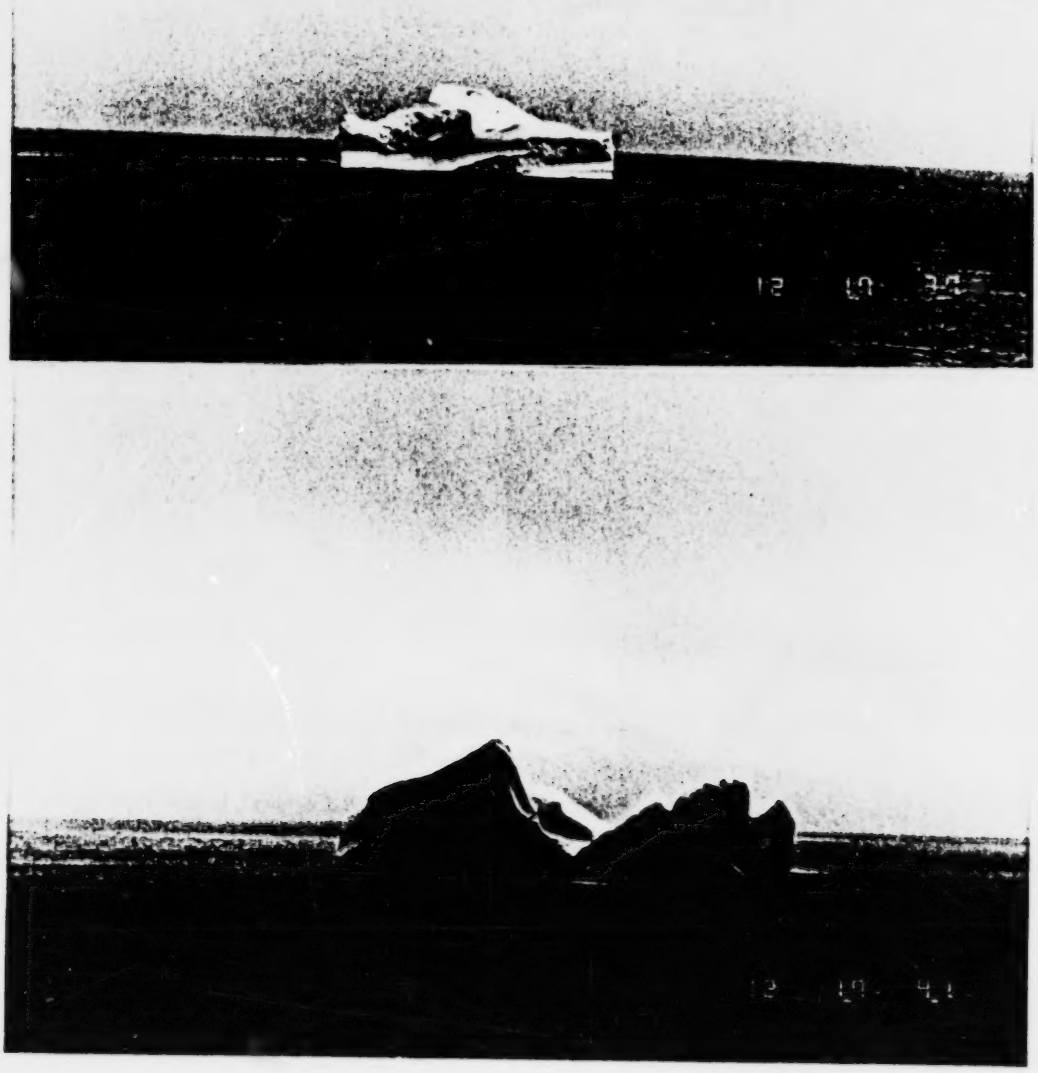
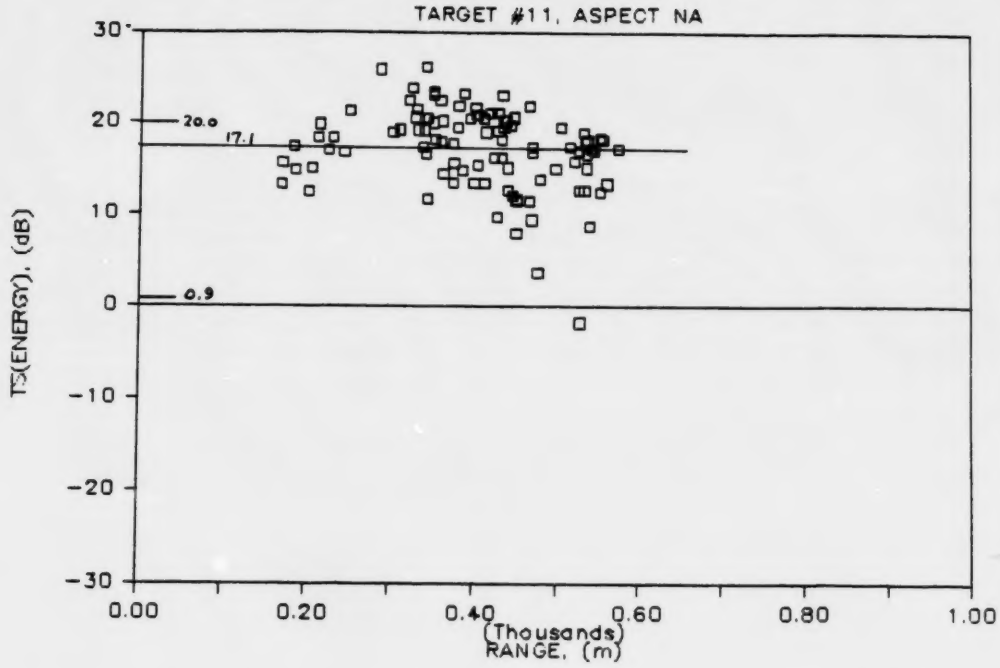
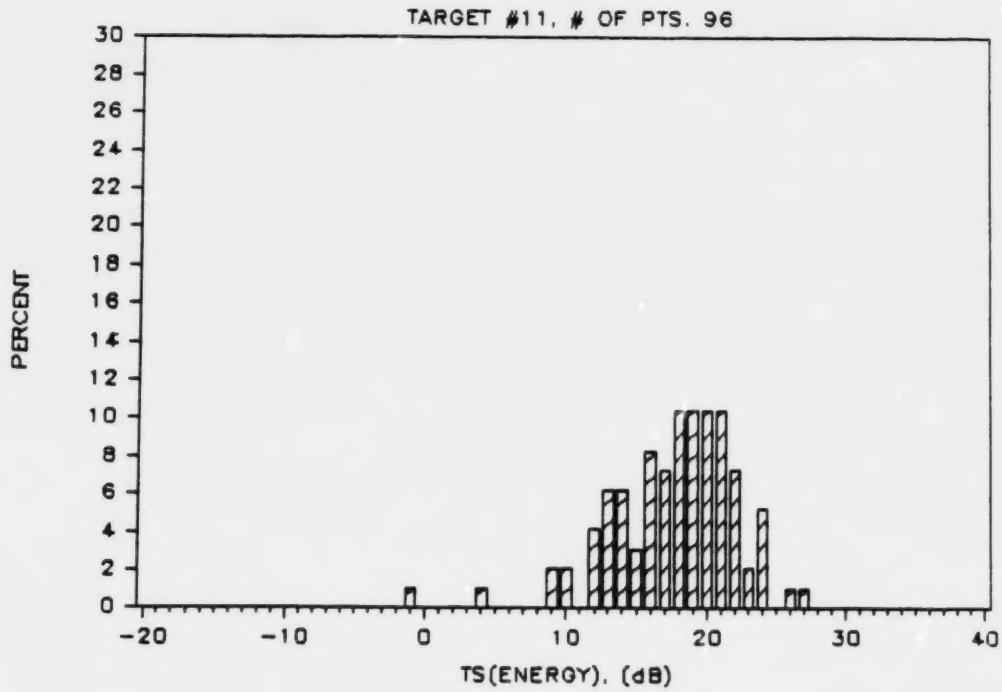
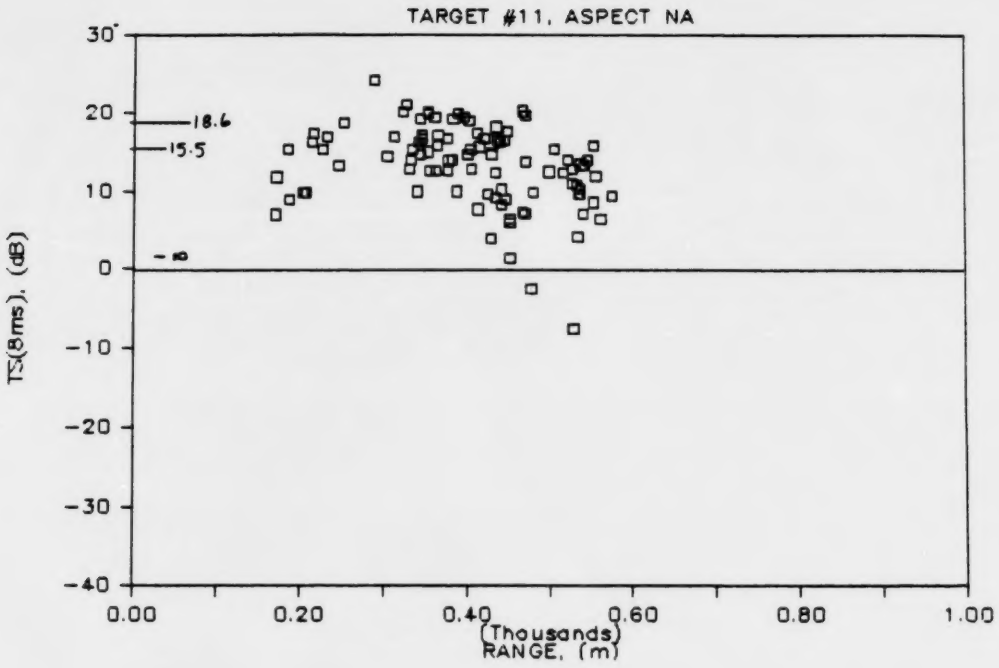
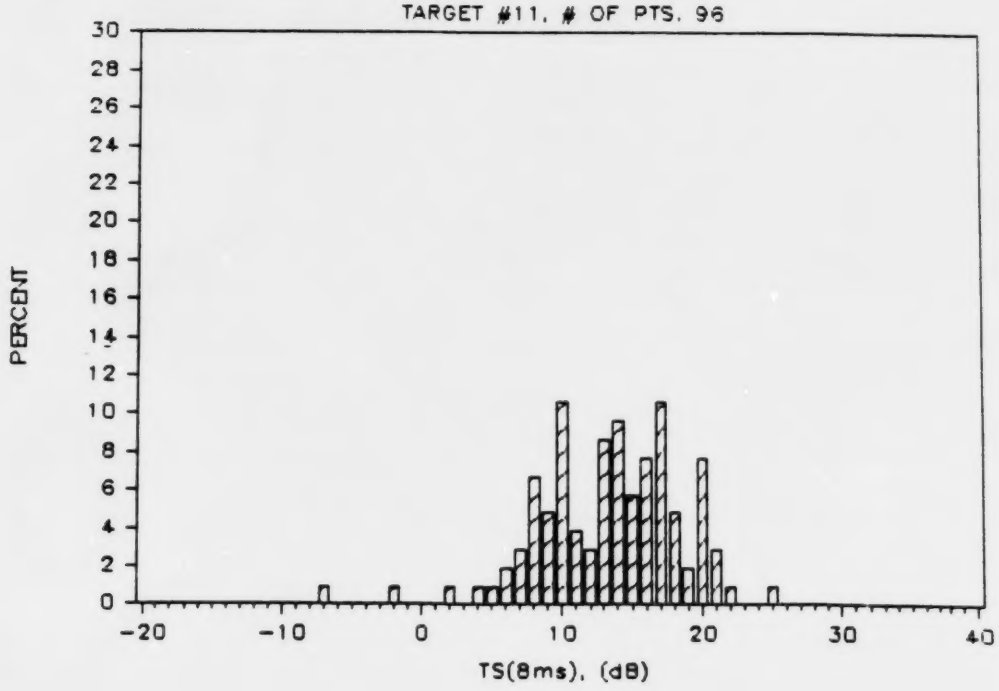


PLATE A15


TARGET #11, ASPECT NA
30
20
10
0
-10
-20
-30
20.0
17.1
0.9
TS(ENERGY), (dB)
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE, (m)


TARGET #11, # OF PTS. 96
PERCENT
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
TS(ENERGY), (dB)


TARGET #11, ASPECT NA
30
20
10
0
-10
-20
-30
-40
18.6
15.5
-∞
TS(8ms), (dB)
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE, (m)


TARGET #11, # OF PTS. 96
PERCENT
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
TS(8ms), (dB)

APPENDIX 5
SOUND SPEED PROFILES AND PROPAGATION PREDICTIONS

This Appendix collects the sound speed profiles that were taken during the trials, together with the propagation predictions based on them.

The profiles are listed in the table below, and the locations of the casts are given on the map Plate 5.1.

Name	Day (GMT)	Time (GMT)	Approx. Position	Comments
Baffin A	7 July 1986	07:28	74°05'N, 80°03'W	observed sound
Baffin B	8 July 1986	00:43	73°35'N, 70°45'W	velocity, compli-
Baffin D	9 July 1986	04:57	73°10'N, 64°39'W	mented by
Baffin C	9 July 1986	08:00	73°10'N, 64°39'W	historical data
Baffin X	9 July 1986	18:26	72°51'N, 60°33'W	
Baffin E	10 July 1986	06:00-13:00	72°30'N, 58°18'W	Historical data only

As the length of the cable of the sound velocity profiles limited the measurement depth to some 110m, the profiles were supplemented by historic data pertaining to the same region and time of year, obtained from the Marine Environmental Data Service of Environment Canada. This procedure is acceptable for the following reasons:

(i) Sound velocity at depths greater than some 50 or 100 m exhibits a much smaller variability than the sound velocity at shallower depths, as it is less affected by the local climate.

(ii) For the situation of interest (a shallow source and target at ranges up to some two kilometers, and a transducer transmitting and receiving close to the horizontal) the propagation takes place only in the shallow layers of the ocean. Therefore, the sound speed profile of deeper layers is of less importance.

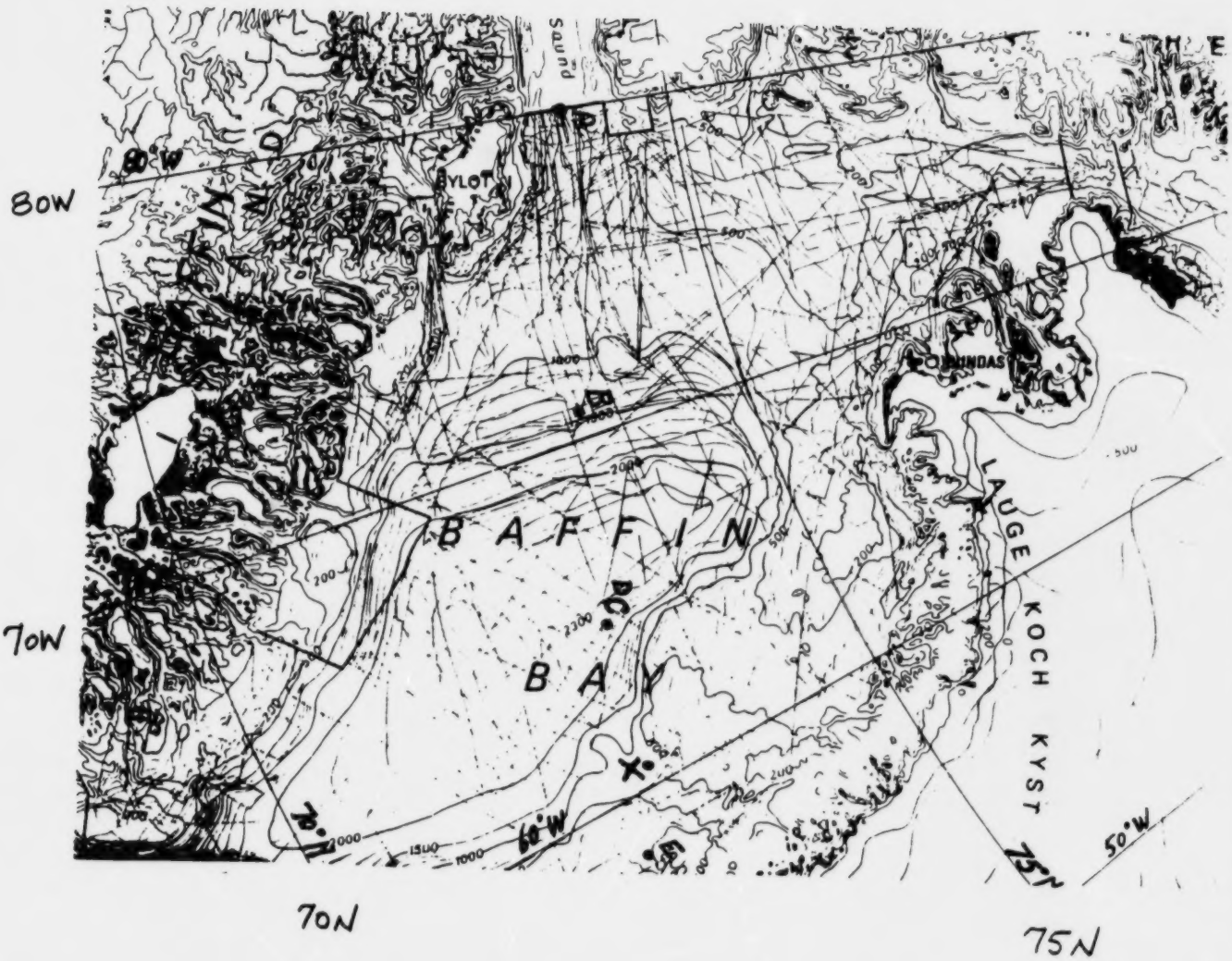


Plate 5.1 Position of Sound Velocity Profile Casts

The profile and propagation data is collected for each of the locations separately, and has the following components:

(i) The temperature and sound velocity profile (as a function of depth). This, as well as the following outputs, is generated by a Canadian Astronautics propagation loss computation program (see Baldour, 1984) based on software contributed by the French Navy.

(ii) The ray-trace diagrams. This shows in the geometrical optics approximation, the way the acoustic energy propagates.

(ii) The (one-way) propagation loss diagram maps propagation loss contours on a range-depth map.

(iv) Finally, the correction to the two-way loss calculation based on spherical spreading and absorption has been plotted for idealized rough targets extending uniformly from the surface to the depth indicated. The correction is based on the integration of the two-way transmission loss calculated by means of the CAL propagation program over the depth dimension of the target.

Examination of the material indicated above suggests two general observations.

(i) The propagation loss corrections are in general small, of the order of a few decibels at most, with the notable exception of ranges at which insonification does not occur at all at the depths considered.

(ii) The near surface propagation critically depends on the values of the near surface sound speed profile. Small sound speed variations in the latter (equivalent to a temperature difference of a few tenths of a degree) can result in very large variations in the propagation loss.

Because of these observations, it was decided that, for the purpose of target strength estimation, it was preferable to correct the received level for spherical spreading and absorption, and exclude other propagation effects. In addition, data obtained at ranges close to the limiting range were not considered in the target calculations.

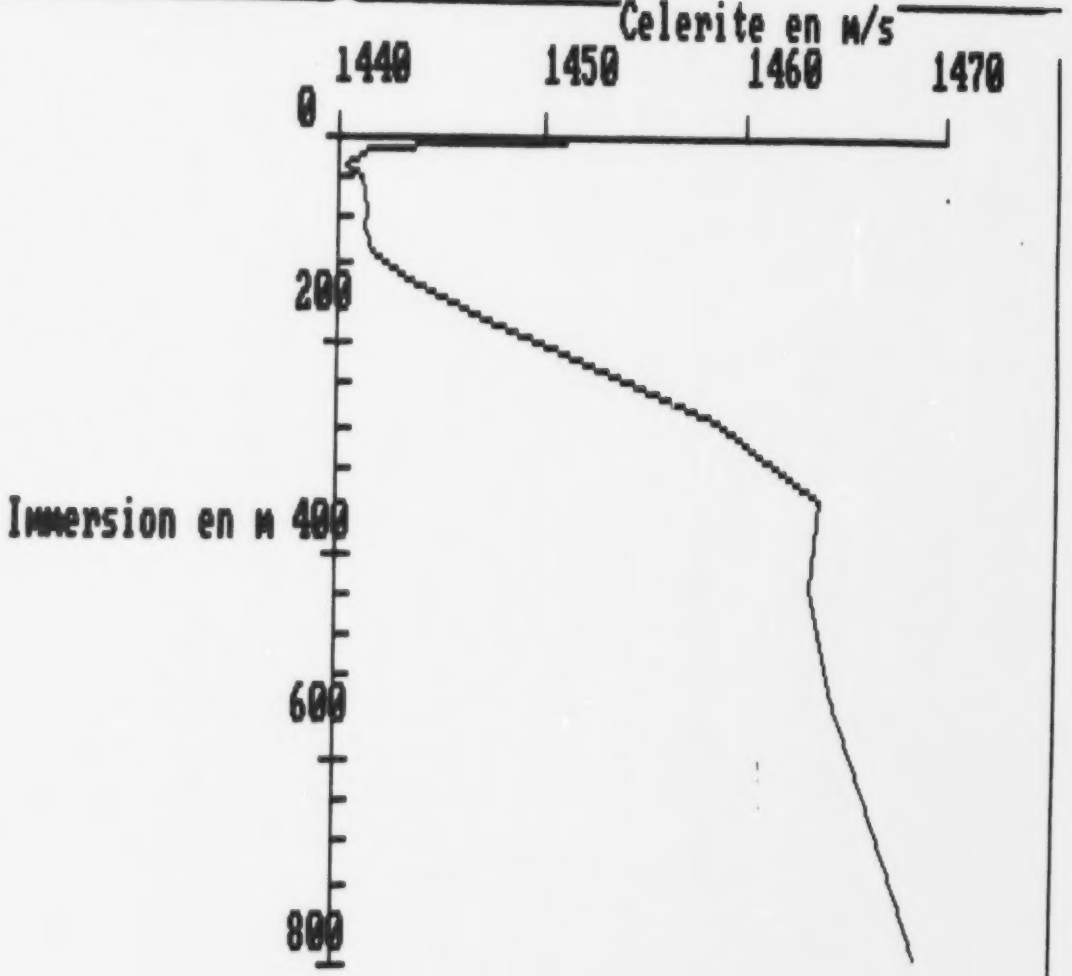
BAFFINA PROFILE

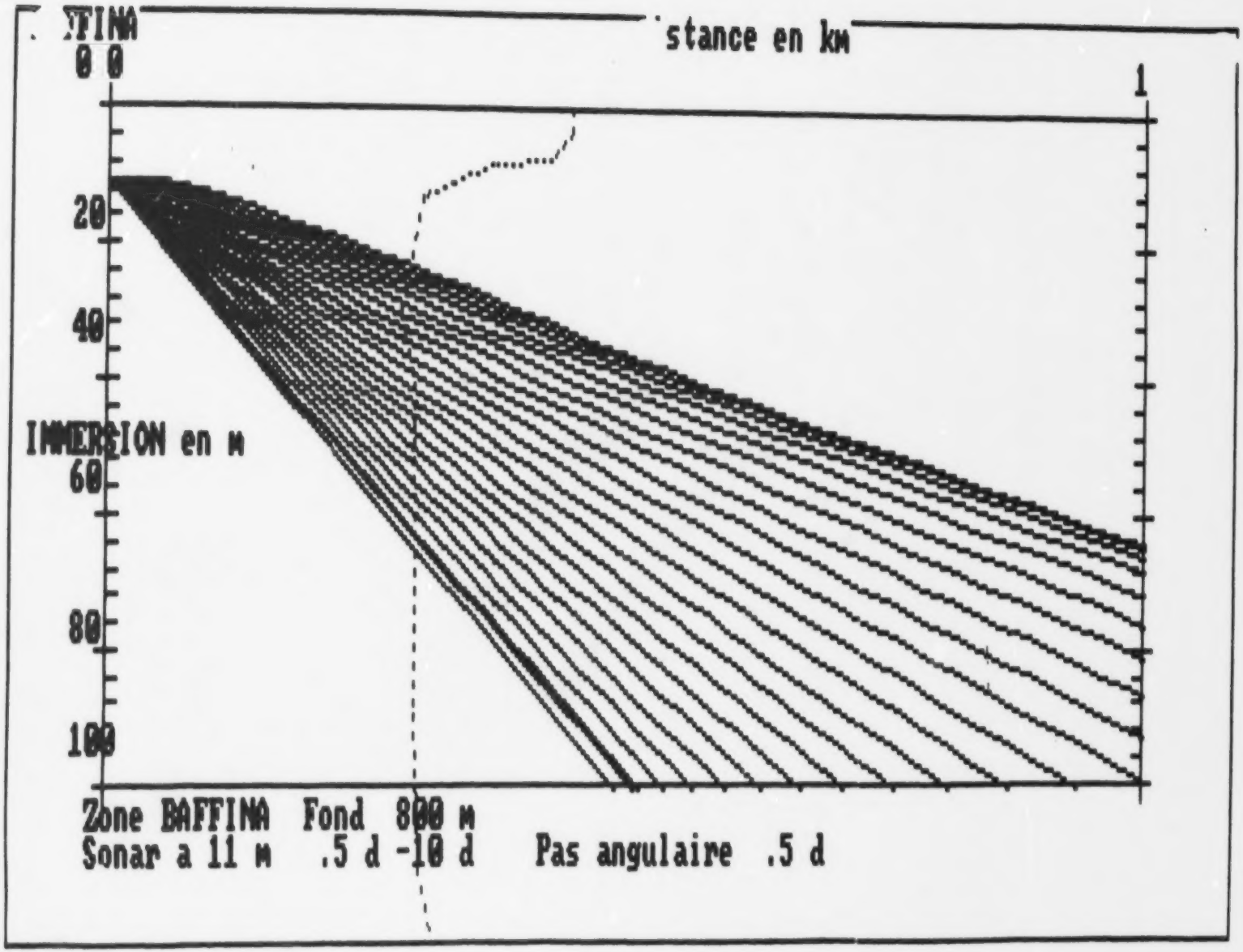
07:28 GMT, 7 July, 1986

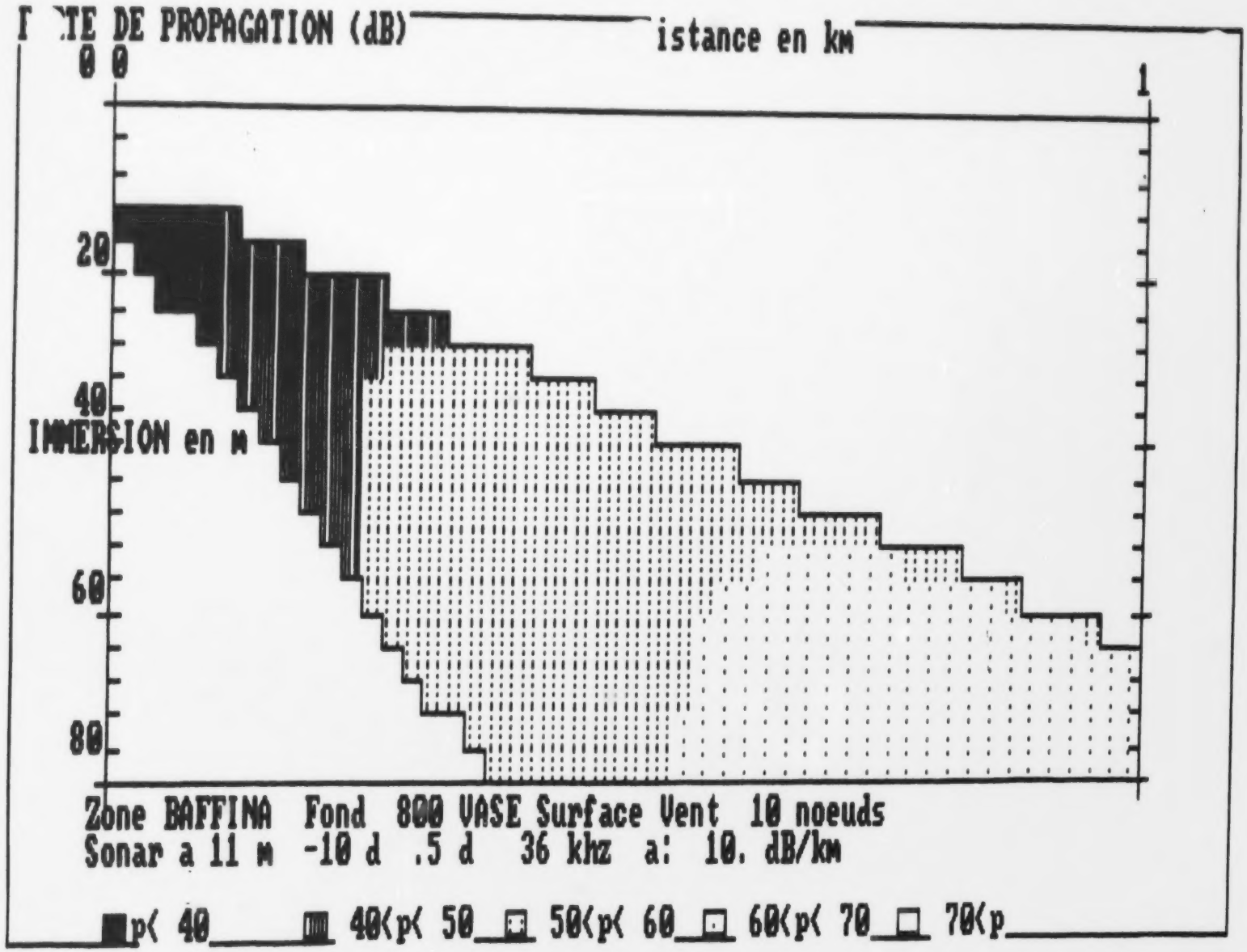
74 05 N, 80 03 W

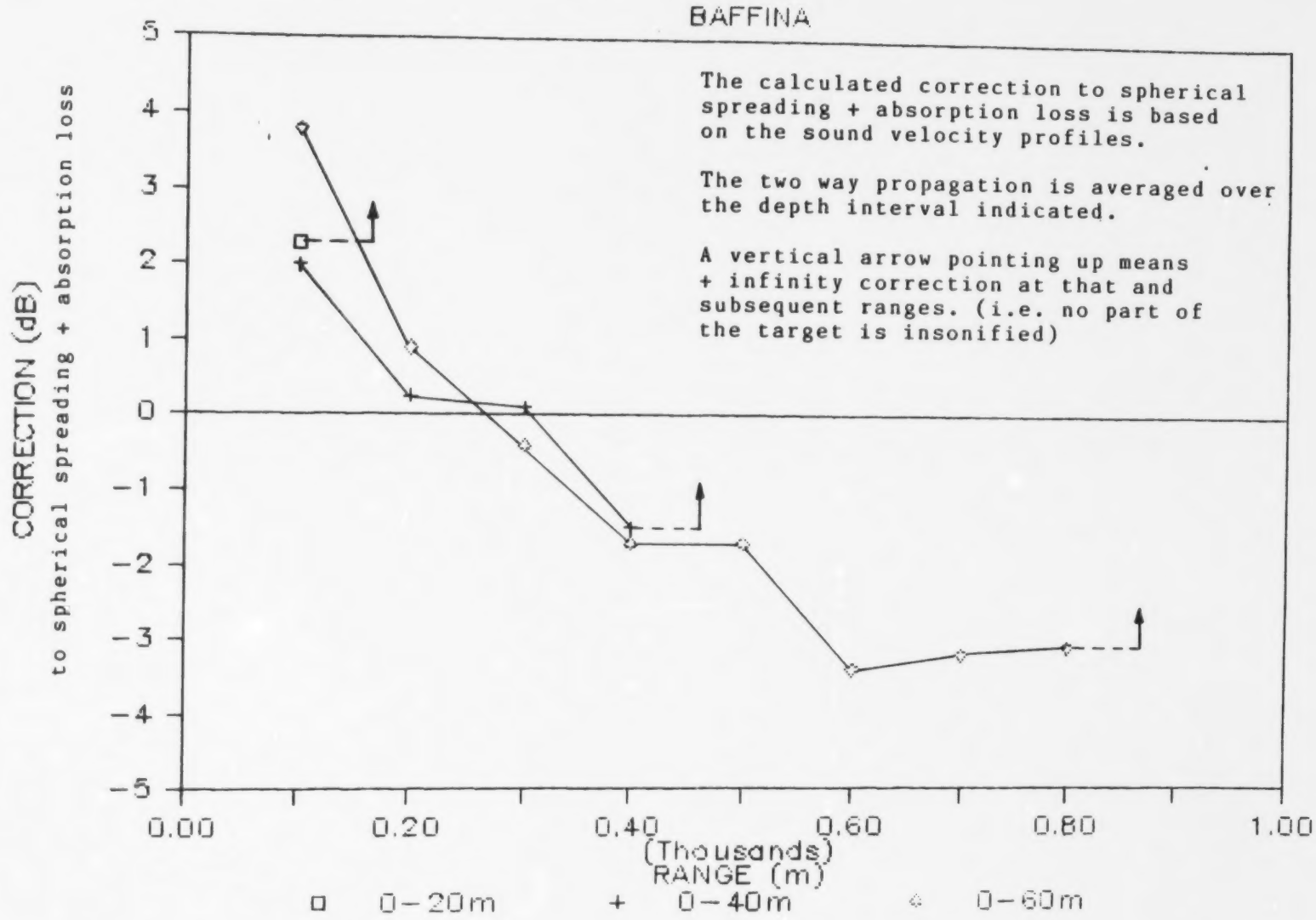
FFINA

n	Imm.(m)	Cel.(m/s)
1	0	1451
2	3.52	1450.98
3	7.59	1449.63
4	7.9	1445.88
5	13.2	1441.5
6	30.05	1440.33
7	40.4	1441.11
8	70.79	1441.29
9	89.5	1441.25
10	112.85	1441.62
11	136.4	1443.45
12	176.8	1447.25
13	277.9	1458.65
14	351.7	1463.75
15	441.7	1463.35
16	537.9	1464.35
17	800	1468.858




FFINA
0 0
stance en km
1
20
40
IMMERSION en m
60
80
100
Zone BAFFINA Fond 800 m
Sonar a 11 m .5 d -10 d Pas angulaire .5 d


I TE DE PROPAGATION (dB)
istance en km
0 0
1
20
40
IMMERSION en M
60
80
Zone BAFFINA Fond 800 VASE Surface Vent 10 noeuds
Sonar a 11 M -10 d .5 d 36 khz a: 10. dB/km
p(40
40(p(50
50(p(60
60(p(70
70(p


BAFFINA
The calculated correction to spherical spreading + absorption loss is based on the sound velocity profiles.
The two way propagation is averaged over the depth interval indicated.
A vertical arrow pointing up means + infinity correction at that and subsequent ranges. (i.e. no part of the target is insonified)
CORRECTION (dB)
to spherical spreading + absorption loss
5
4
3
2
1
0
-1
-2
-3
-4
-5
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE (m)
□ 0-20m
+ 0-40m
◇ 0-60m

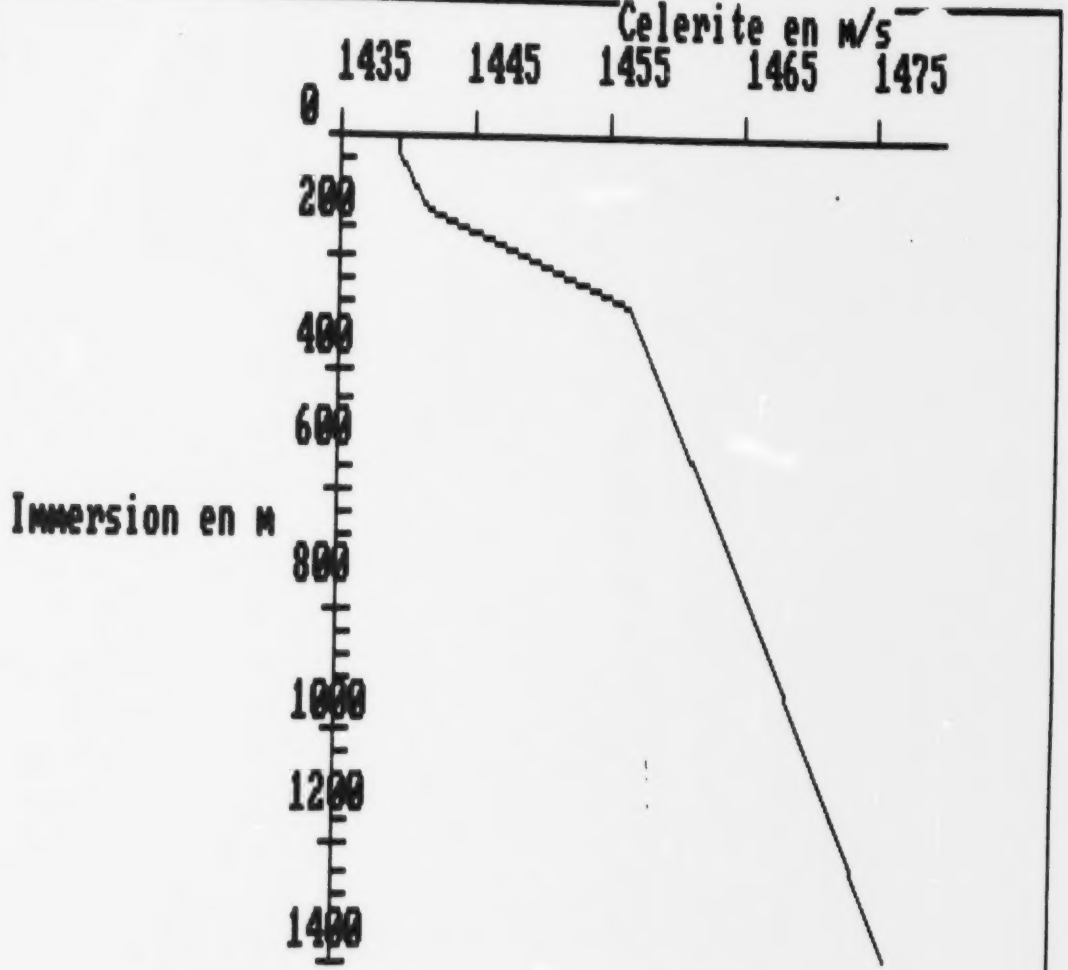
BAFFINB PROFILE

00:43 GMT, 8 July, 1986

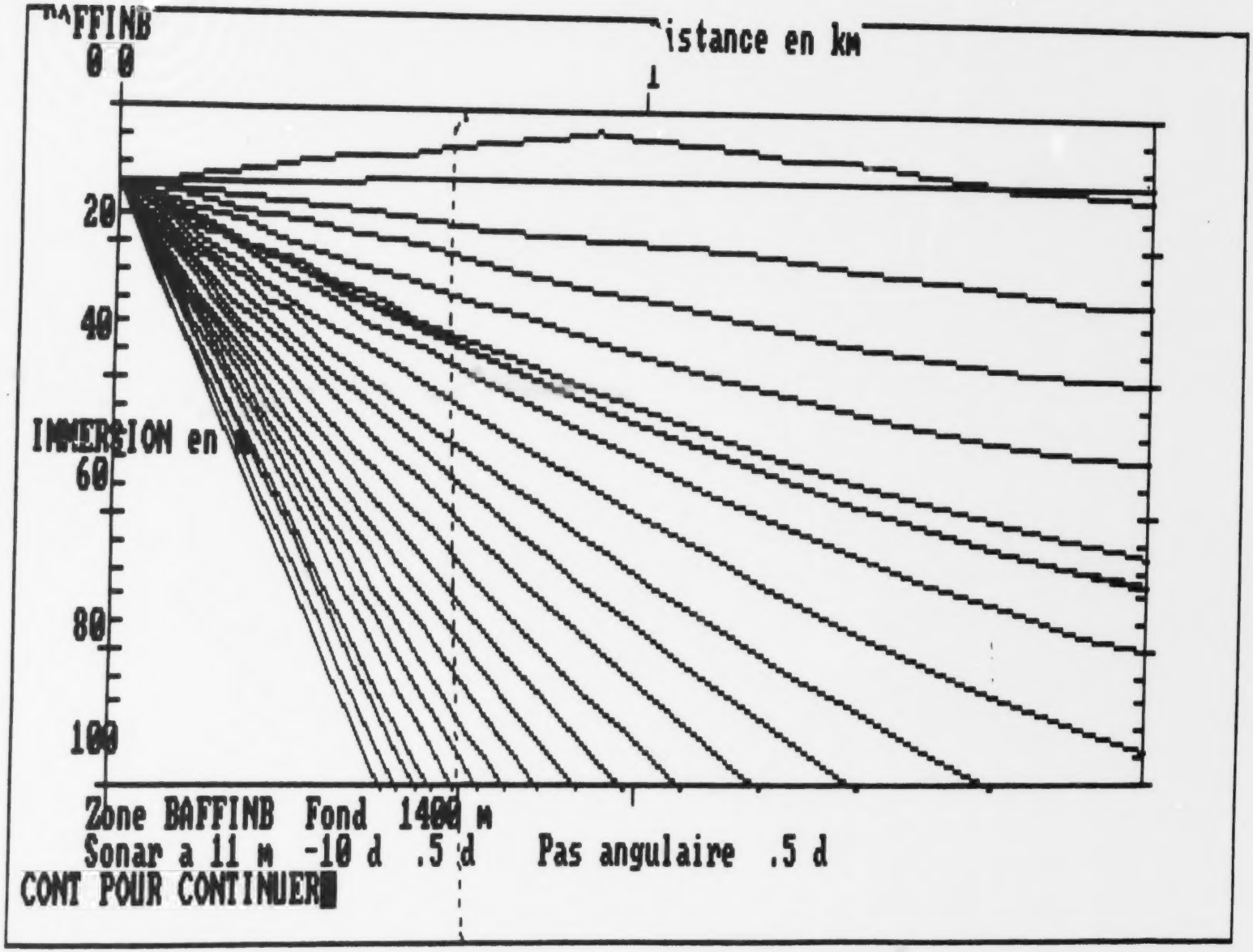
73 35 N, 70 45 W

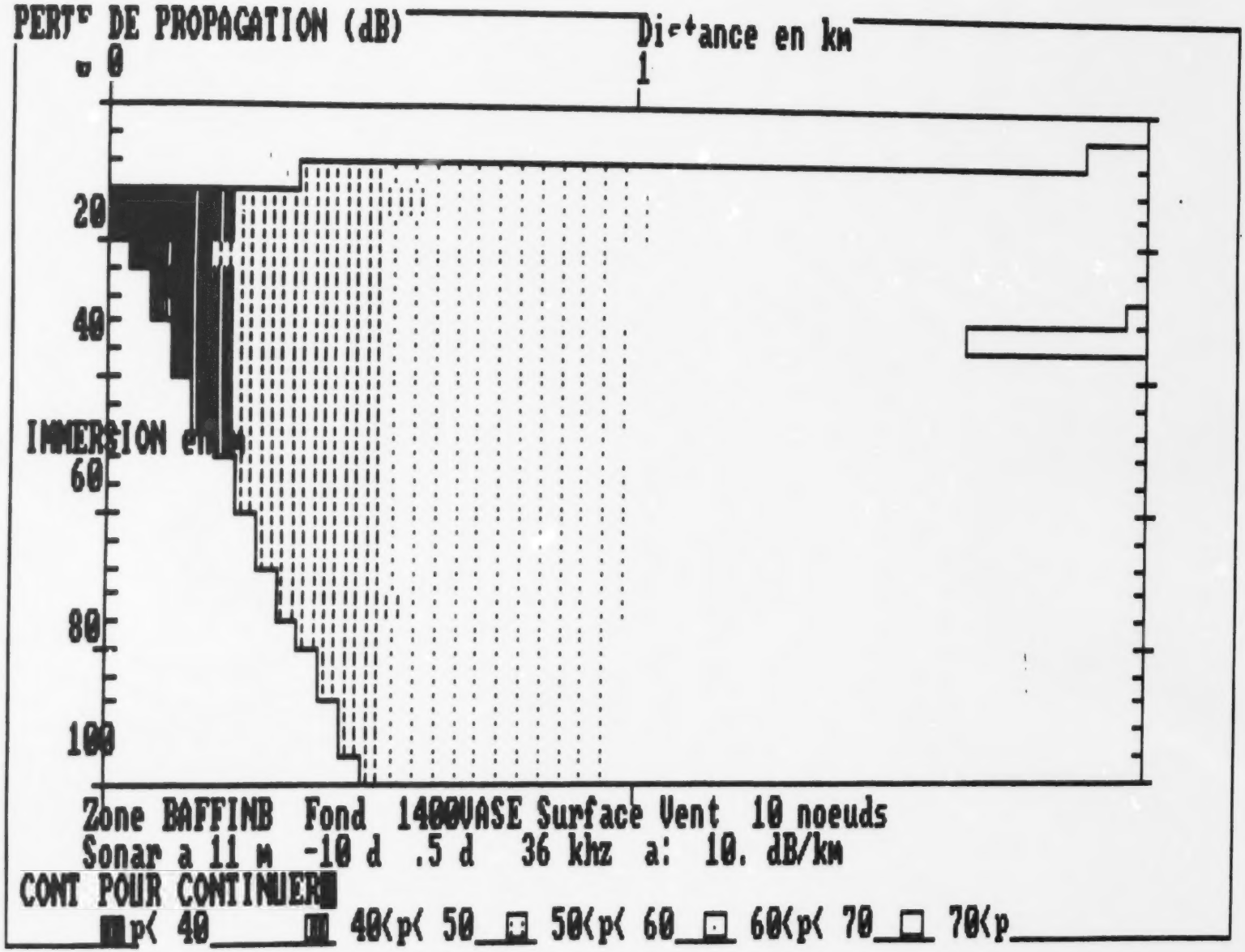
BAFFINB

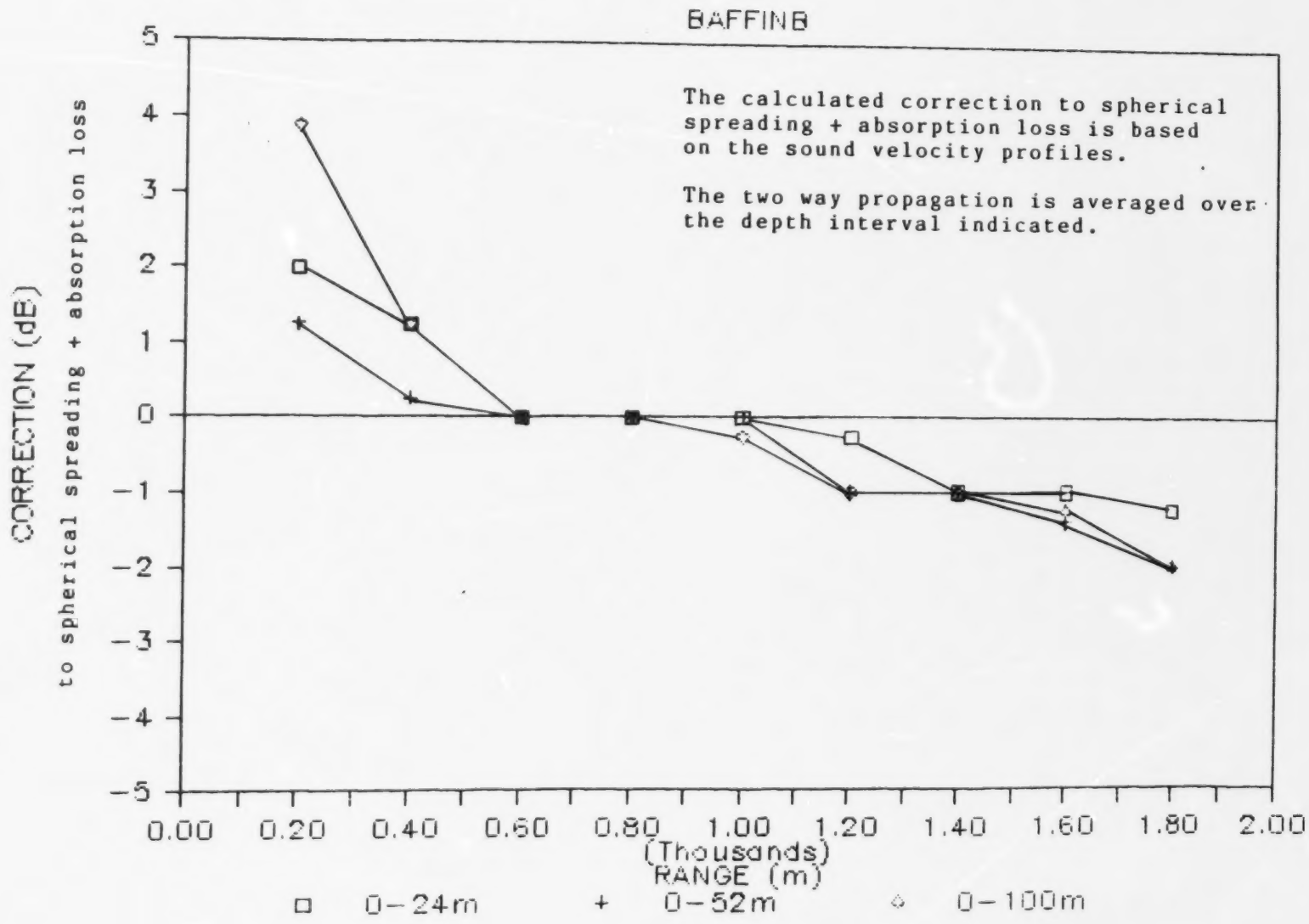
n	Imm.(m)	Cel.(m/s)
1	0	1440.09
2	1.25	1440.3
3	2.5	1439.29
4	30.67	1439.29
5	70.06	1440.08
6	122.54	1441.46
7	295	1456.6
8	803.3	1465.9
9	1400	1476.163



Bathy correct ? O


istance en km
1
0 0
20
40
60
80
100
Zone BAFFINB Fond 1400 m
Sonar a 11 m -10 d .5 d Pas angulaire .5 d
CONT POUR CONTINUER


PERTE DE PROPAGATION (dB)
Distance en km
0
1
20
40
IMMERSION en m
60
80
100
Zone BAFFINB Fond 1400VASE Surface Vent 10 noeuds
Sonar a 11 m -10 d .5 d 36 khz a: 10. dB/km
CONT POUR CONTINUER
p< 40
40<p< 50
50<p< 60
60<p< 70
70<p


BAFFINB
The calculated correction to spherical spreading + absorption loss is based on the sound velocity profiles.
The two way propagation is averaged over the depth interval indicated.
CORRECTION (dB)
to spherical spreading + absorption loss
5
4
3
2
1
0
−1
−2
−3
−4
−5
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
(Thousands)
RANGE (m)
□ 0−24m
+ 0−52m
◇ 0−100m

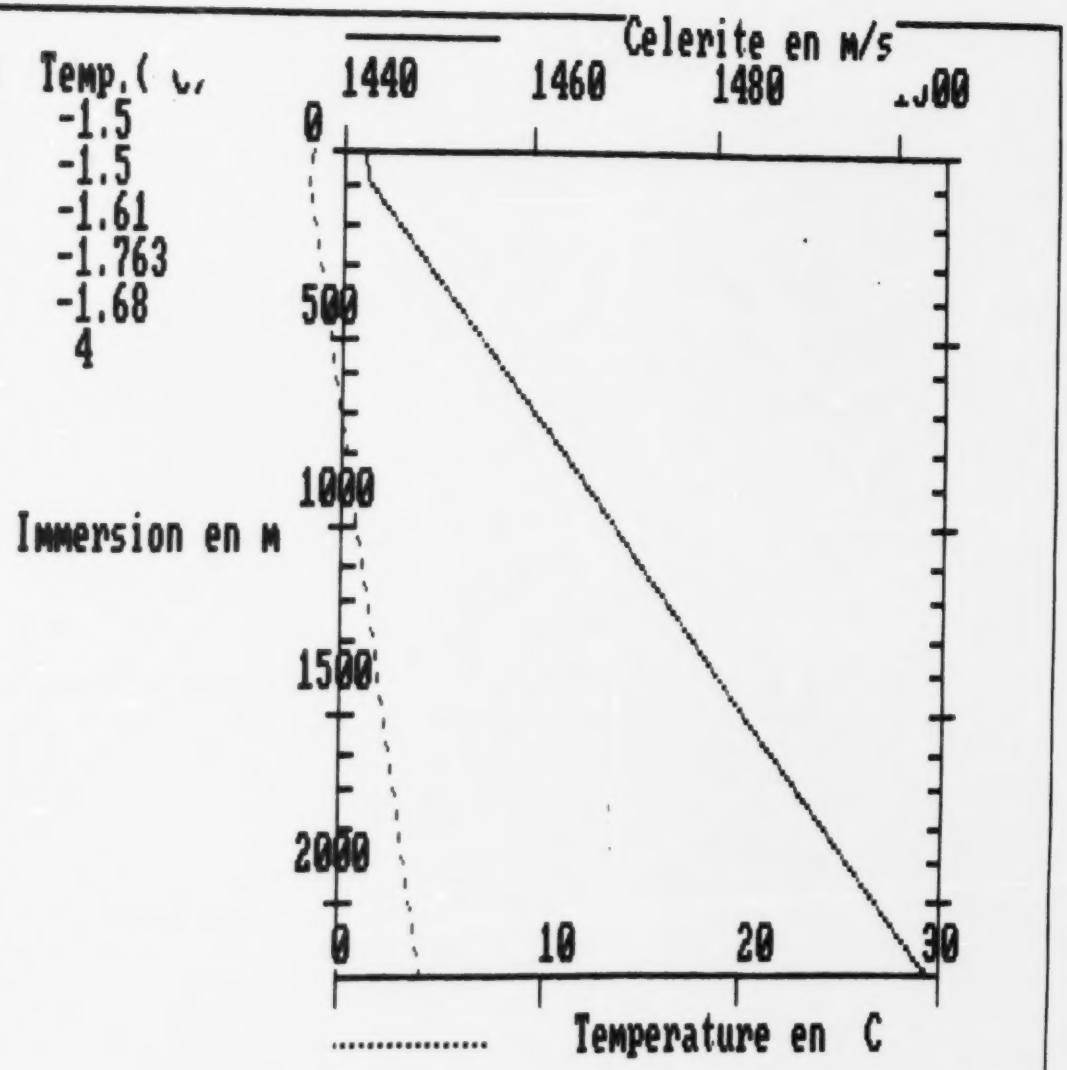
BAFFIND PROFILE

04:57 GMT, 9 July, 1986

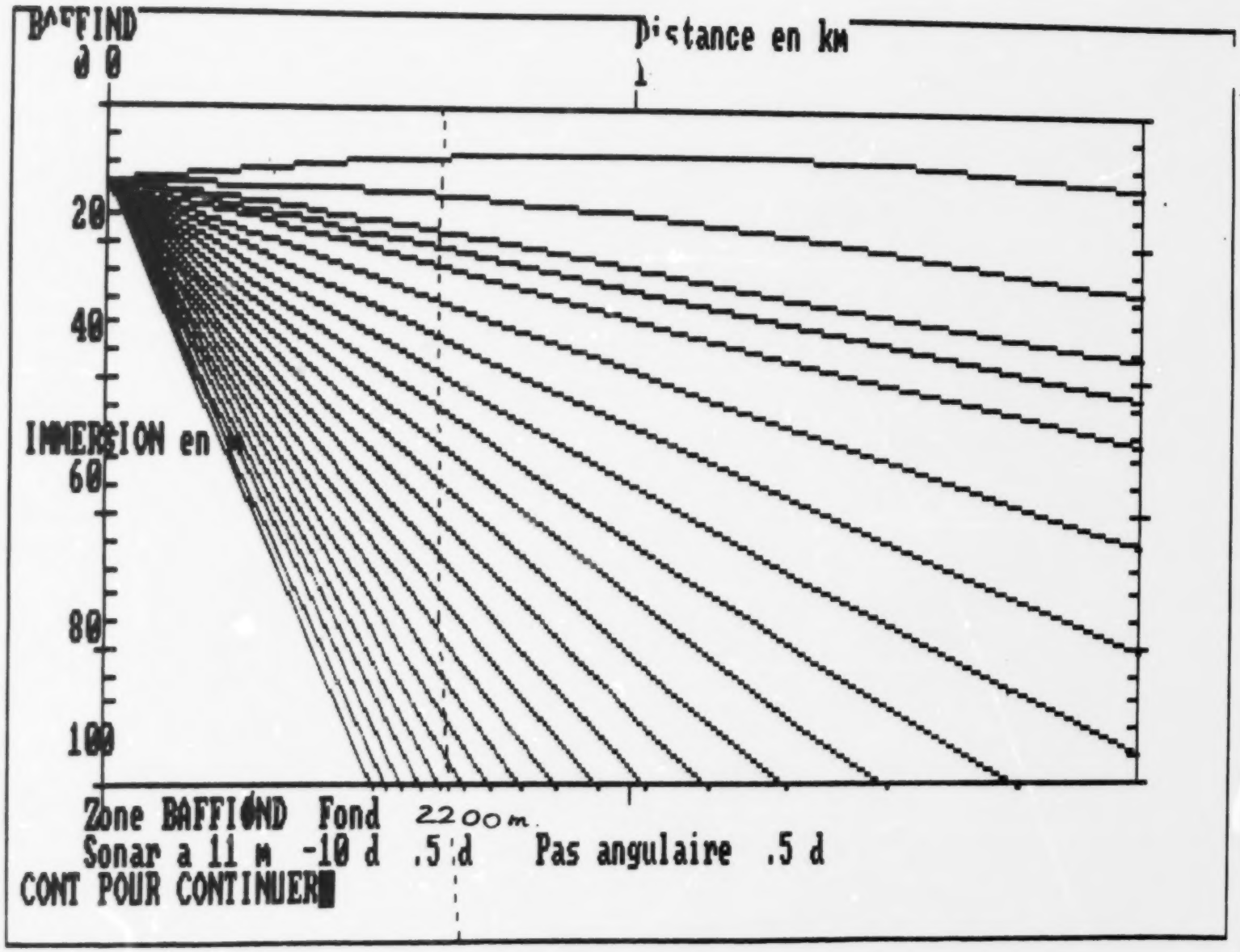
73 10 N, 64 39 W

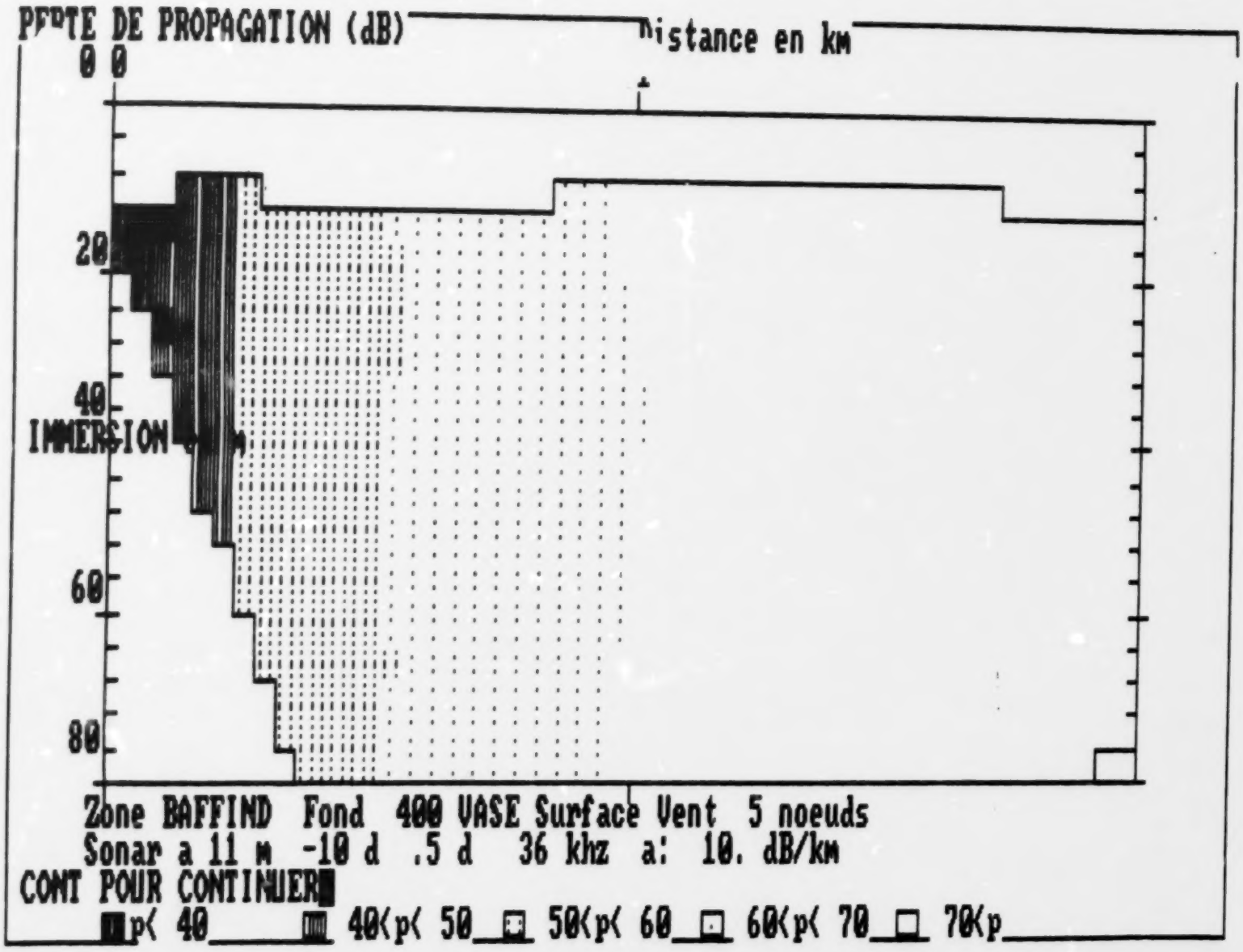
BAFFIND2200

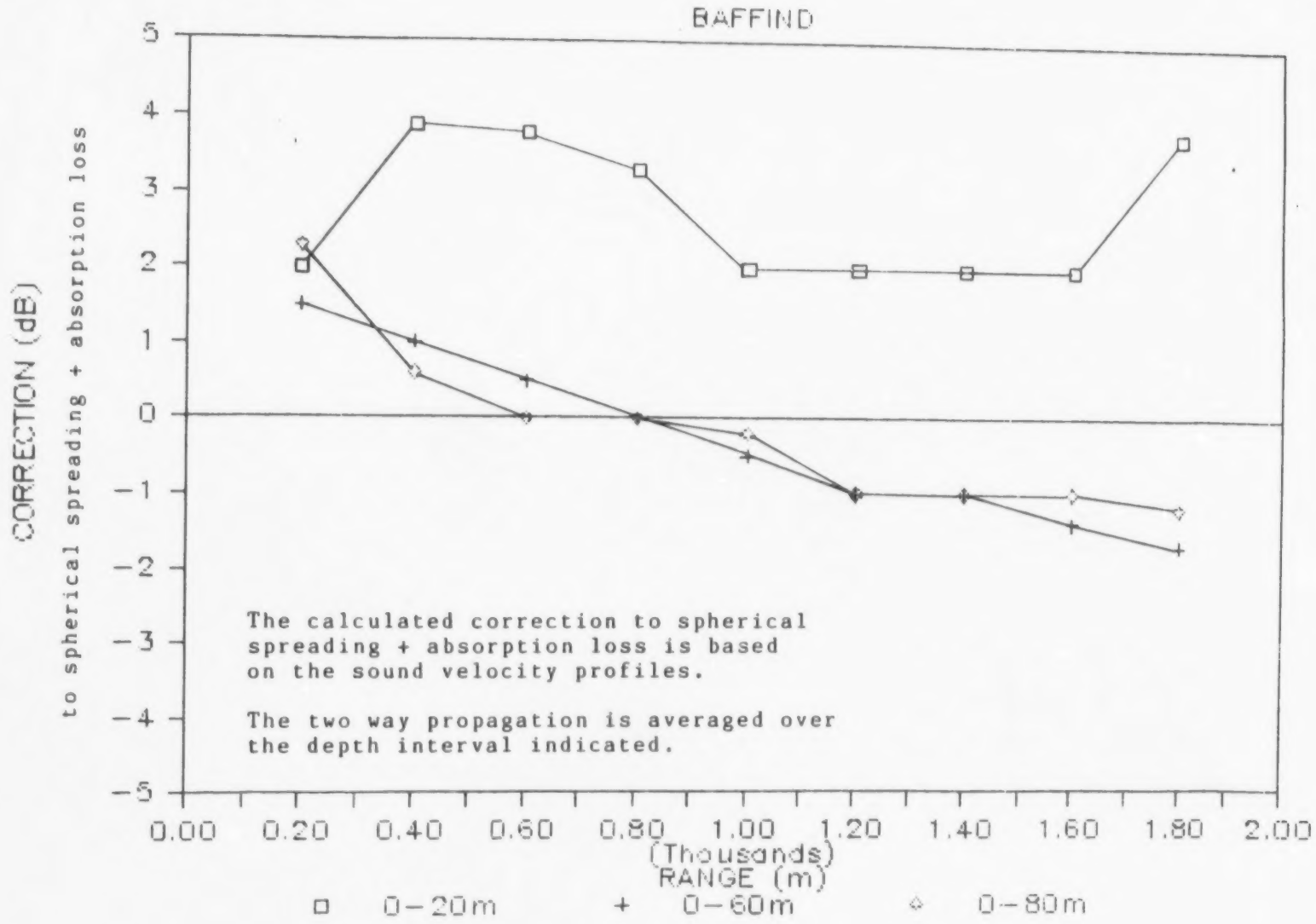
n	Imm.(m)	Cel.(m/s)	Temp.(
1	0	1442.43	-1.5
2	1.64	1442.456	-1.5
3	19.53	1442.227	-1.61
4	75.5	1442.417	-1.763
5	124	1443.613	-1.68
6	2200	1503.764	4



Bathy correct ?


BAFFIND
0 0
Distance en km
1
20
40
IMMERSION en m
60
80
100
Zone BAFFIND Fond 2200m
Sonar a 11 m -10 d .5 d Pas angulaire .5 d
CONT POUR CONTINUER


PERTE DE PROPAGATION (dB)
Distance en km
0 0
20
40
IMMERSION
60
80
Zone BAFFIND Fond 400 VASE Surface Vent 5 noeuds
Sonar a 11 m -10 d .5 d 36 khz a: 10. dB/km
CONT POUR CONTINUER
p< 40
40<p< 50
50<p< 60
60<p< 70
70<p


BAFFIND
CORRECTION (dB)
to spherical spreading + absorption loss
5
4
3
2
1
0
−1
−2
−3
−4
−5
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
(Thousands)
RANGE (m)
The calculated correction to spherical spreading + absorption loss is based on the sound velocity profiles.
The two way propagation is averaged over the depth interval indicated.
0−20m
0−60m
0−80m

BAFFINC PROFILE

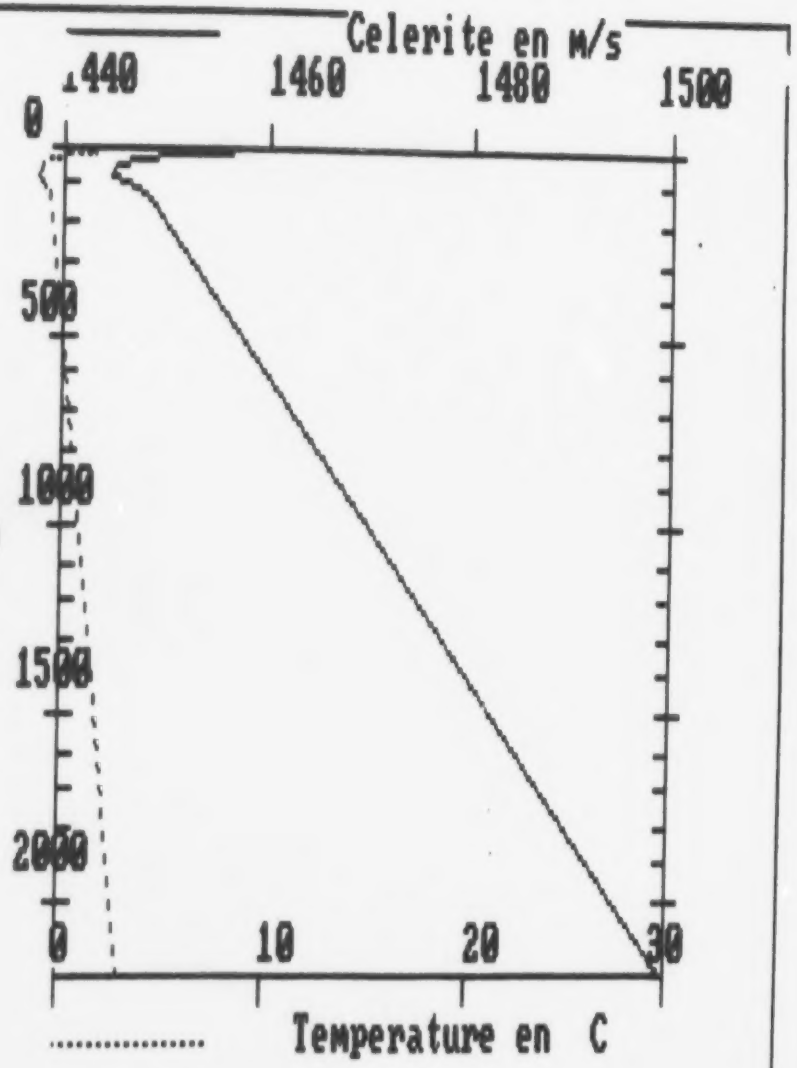
08:00 GMT, 9 July, 1986

73 10 N, 64 39 W

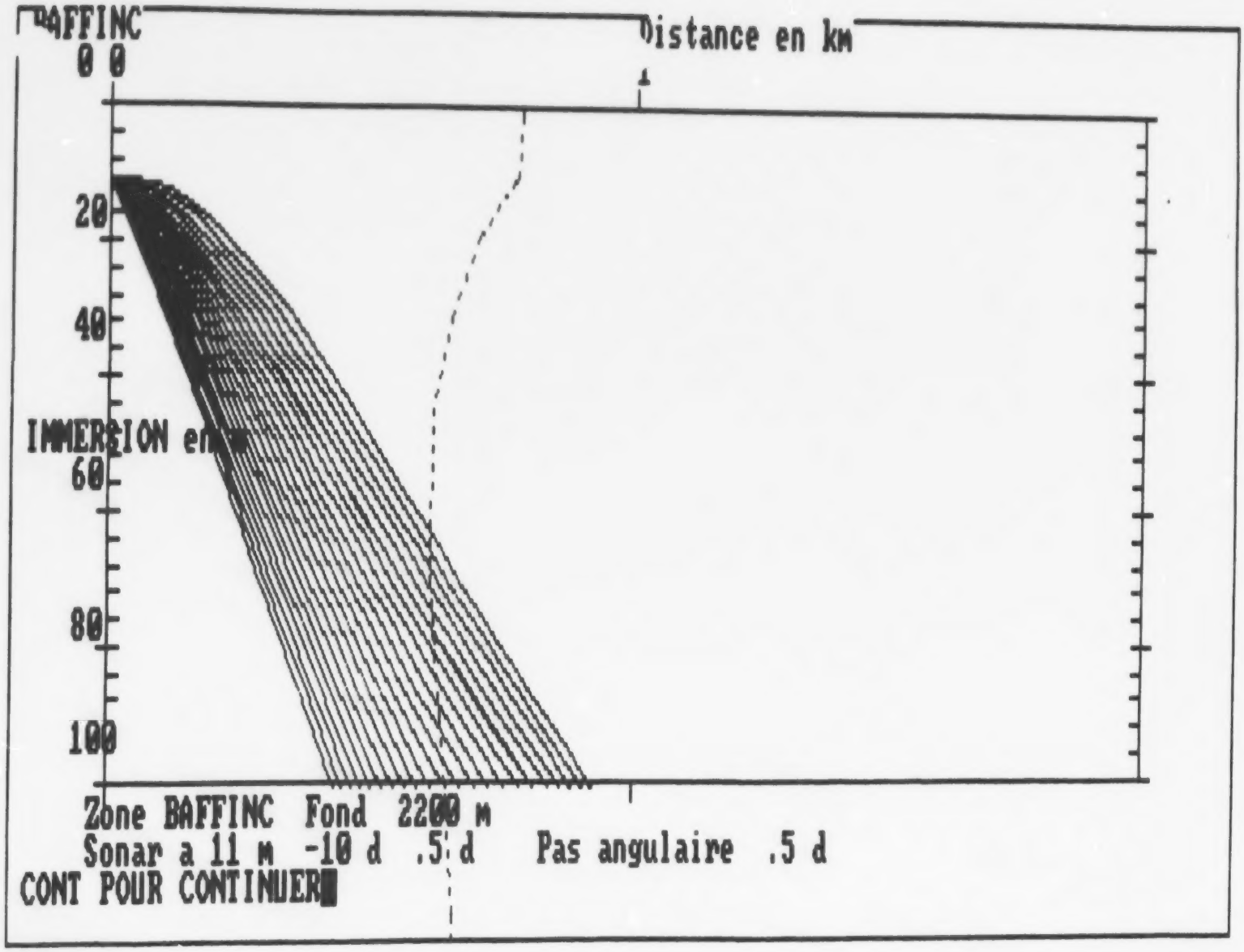
AFFINC

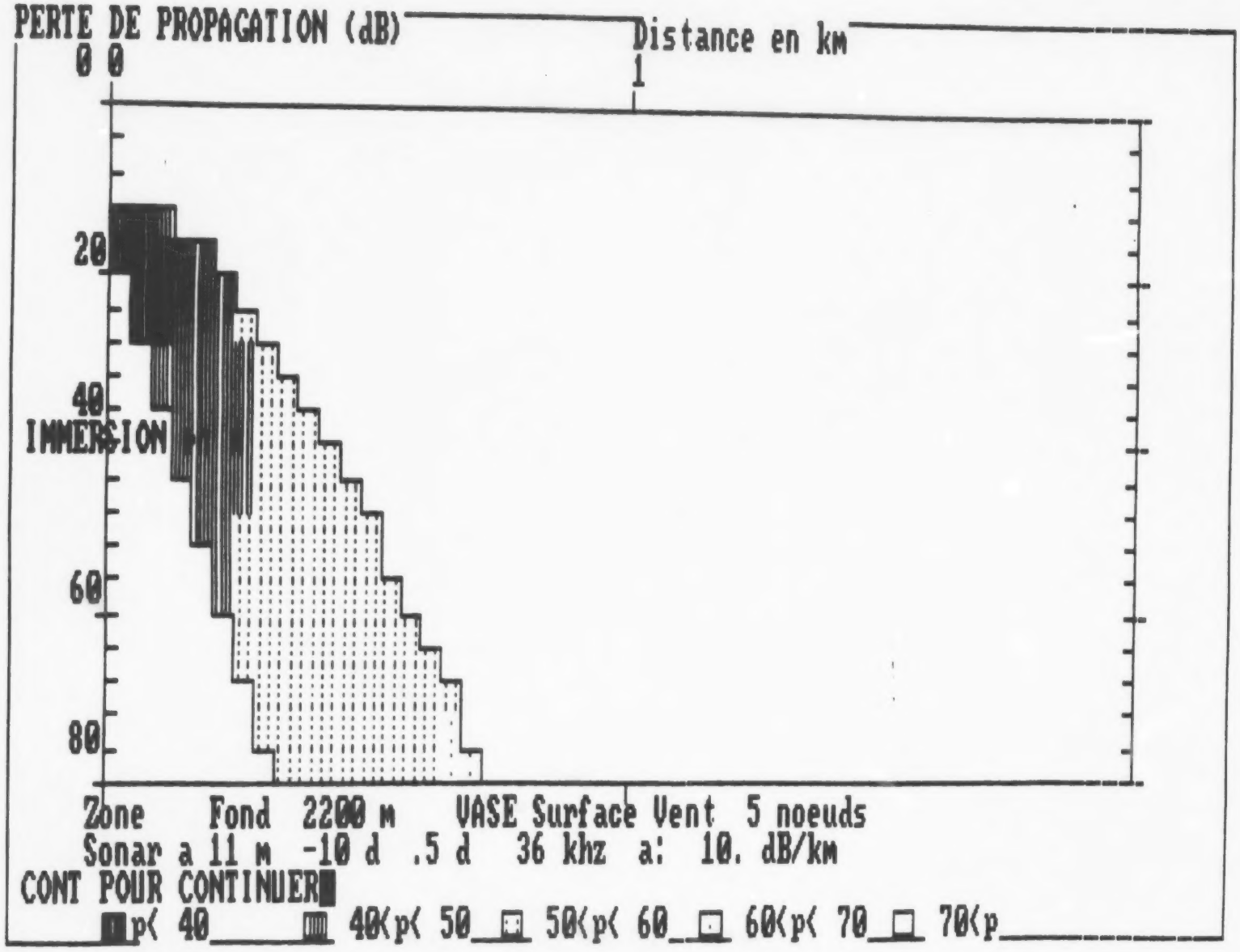
n	Imm.(m)	Cel.(m/s)	Temp.(C)
1	0	1456.651	1.6
2	1.19	1456.671	1.6
3	10.4	1456.113	1.44
4	18.99	1450.851	.24
5	31.15	1447.201	-.595
6	44.8	1444.966	-1.12
7	70.1	1444.579	-1.29
8	91.31	1446.202	-1.02
9	119.93	1447.972	-.743
10	2200	1499.567	Immersion en m

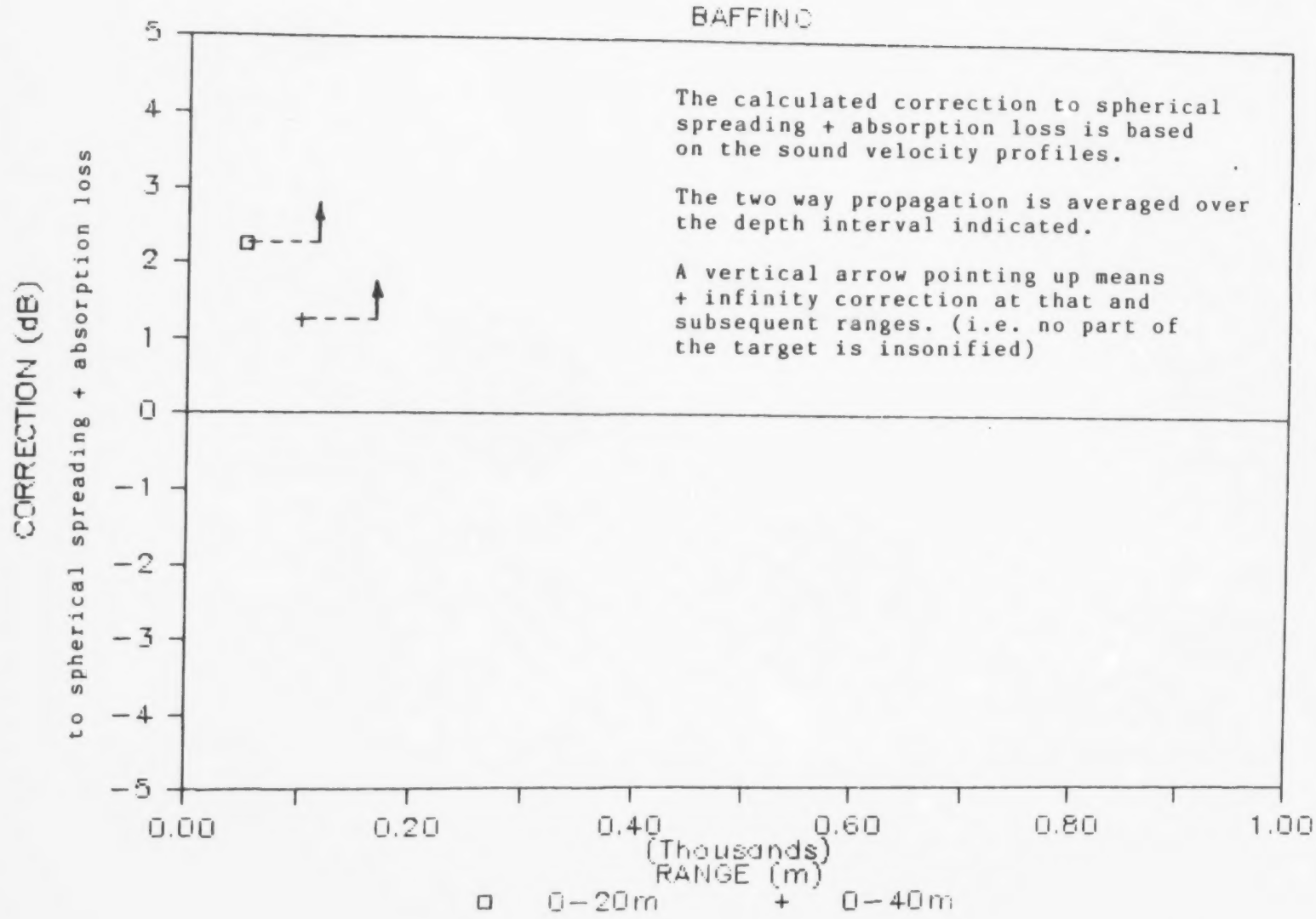
→ 3'



Bathy correct ?


BAFFINC
0 0
Distance en km
20
40
IMMERSION en m
60
80
100
Zone BAFFINC Fond 2200 m
Sonar a 11 m -10 d .5 d Pas angulaire .5 d
CONT POUR CONTINUER


PERTE DE PROPAGATION (dB)
0 0
Distance en km
1
20
40
IMMERSION
60
80
Zone Fond 2200 m VASE Surface Vent 5 noeuds
Sonar a 11 m -10 d .5 d 36 khz a: 10. dB/km
CONT POUR CONTINUER
p< 40
40<p< 50
50<p< 60
60<p< 70
70<p


BAFFIN
The calculated correction to spherical spreading + absorption loss is based on the sound velocity profiles.
The two way propagation is averaged over the depth interval indicated.
A vertical arrow pointing up means + infinity correction at that and subsequent ranges. (i.e. no part of the target is insonified)
CORRECTION (dB)
to spherical spreading + absorption loss
5
4
3
2
1
0
-1
-2
-3
-4
-5
0.00
0.20
0.40
0.60
0.80
1.00
(Thousands)
RANGE (m)
□ 0-20m
+ 0-40m

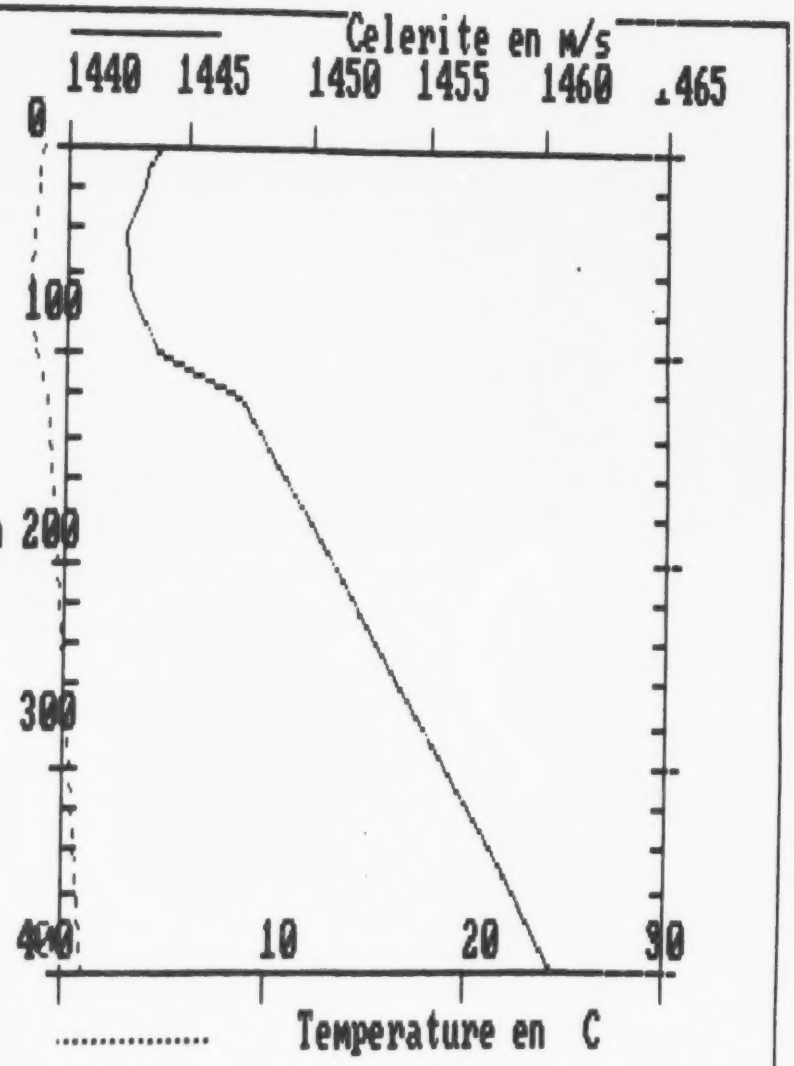
BAFFINX PROFILE

18:26 GMT, 9 July, 1986

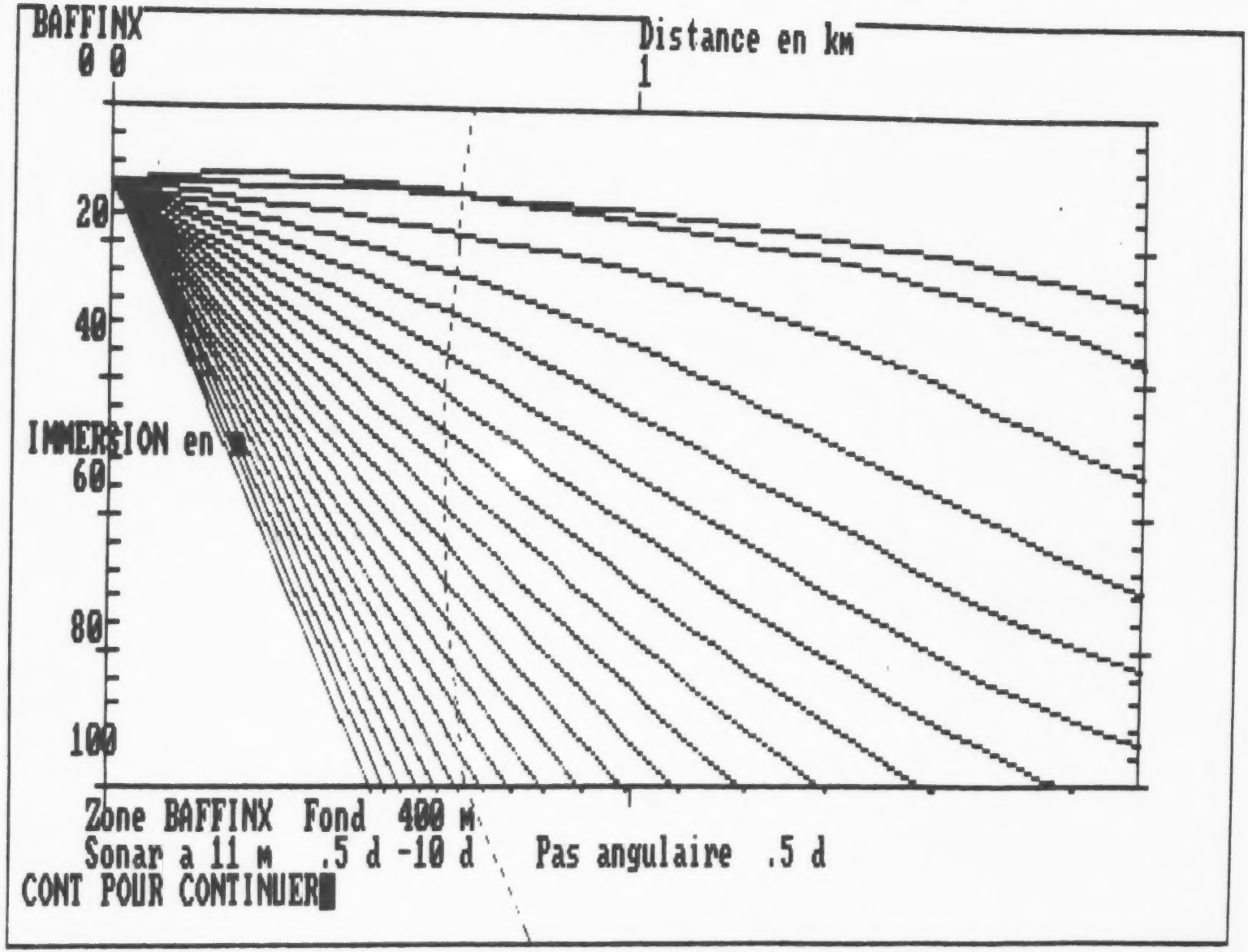
72 51 N, 60 33 W

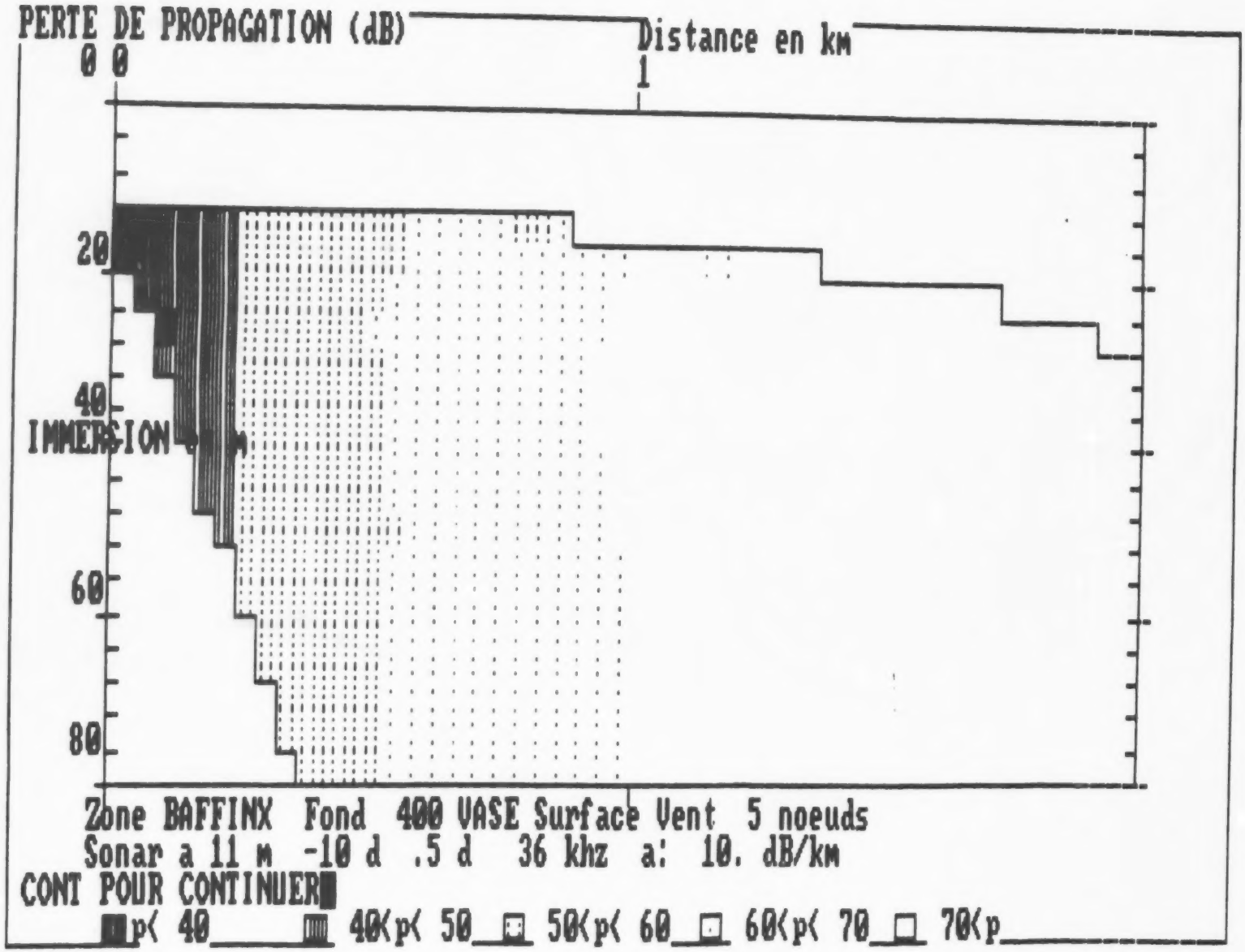
BAFFINX

n	Imm.(m)	Cel.(m/s)	Temp.(C,
1	0	1443.851	-1.2
2	10.61	1443.221	-1.37
3	20.93	1443.106	-1.43
4	40.88	1442.34	-1.66
5	70.1	1442.582	-1.71
6	99.11	1443.68	-1.58
7	122	1447.13	-.93
8	400	1460.577	1



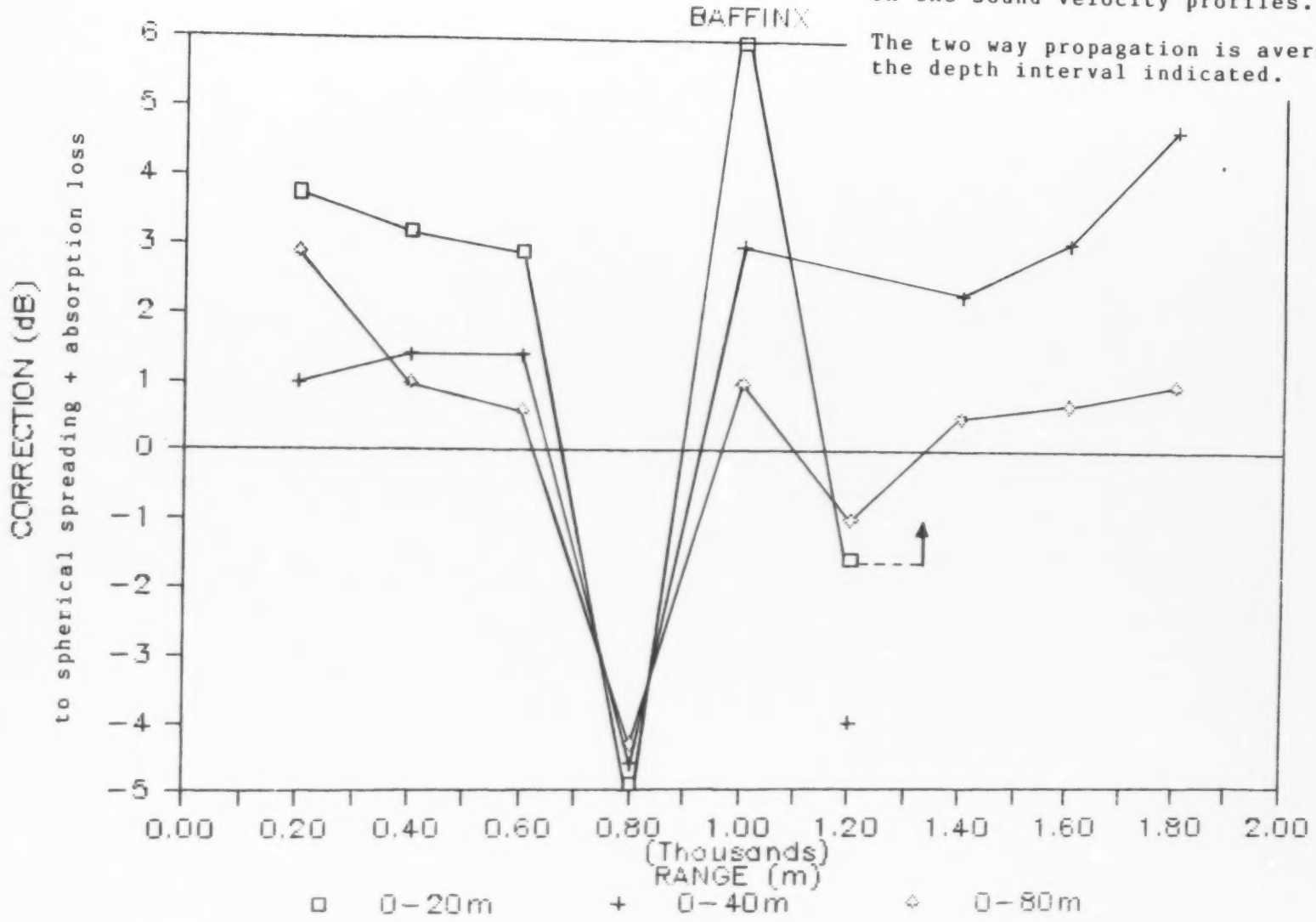
Bathy correct ? 0


BAFFINX
0 0
Distance en km
1
20
40
IMMERSION en m
60
80
100
Zone BAFFINX Fond 400 m
Sonar a 11 m .5 d -10 d Pas angulaire .5 d
CONT POUR CONTINUER


PERTE DE PROPAGATION (dB)
Distance en km
0 0
1
20
40
IMMERSION
60
80
Zone BAFFINX Fond 400 VASE Surface Vent 5 noeuds
Sonar a 11 m -10 d .5 d 36 khz a: 10. dB/km
CONT POUR CONTINUER
p< 40
40<p< 50
50<p< 60
60<p< 70
70<p

The calculated correction to spherical spreading + absorption loss is based on the sound velocity profiles.

The two way propagation is averaged over the depth interval indicated.



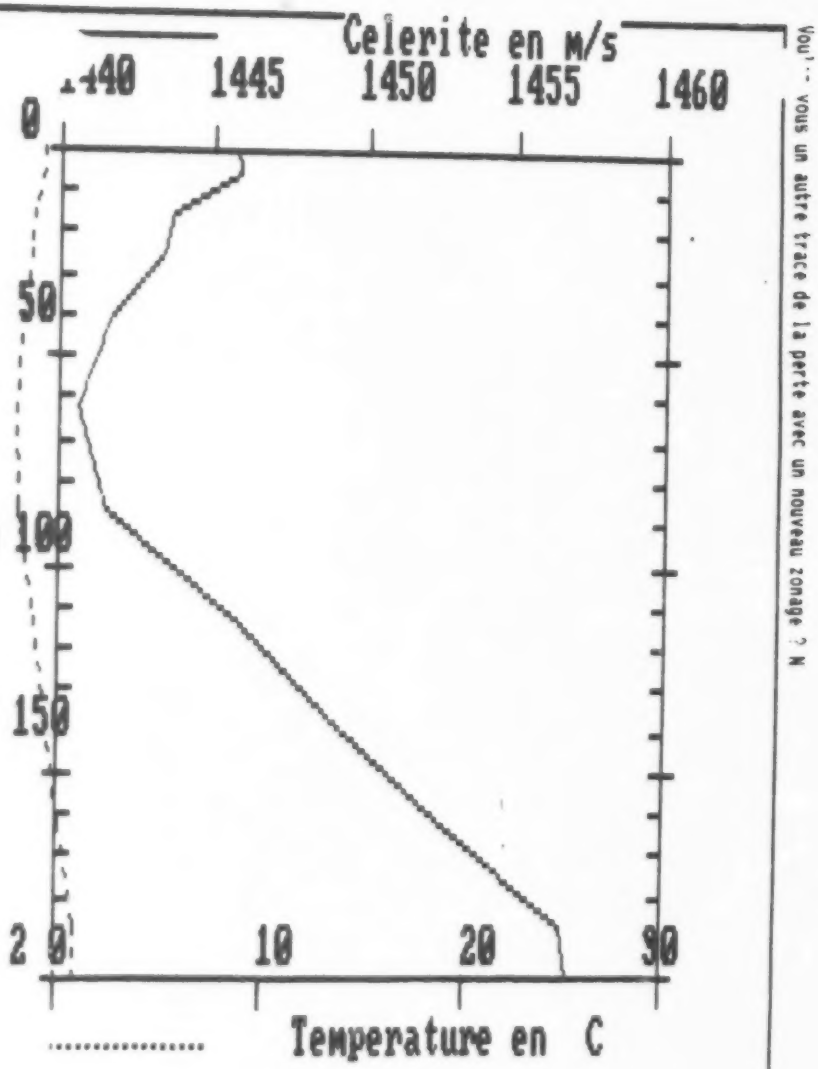
BAFFINE PROFILE

06:00-13:30 GMT, 10 July, 1986

72 30 N, 58 18 W

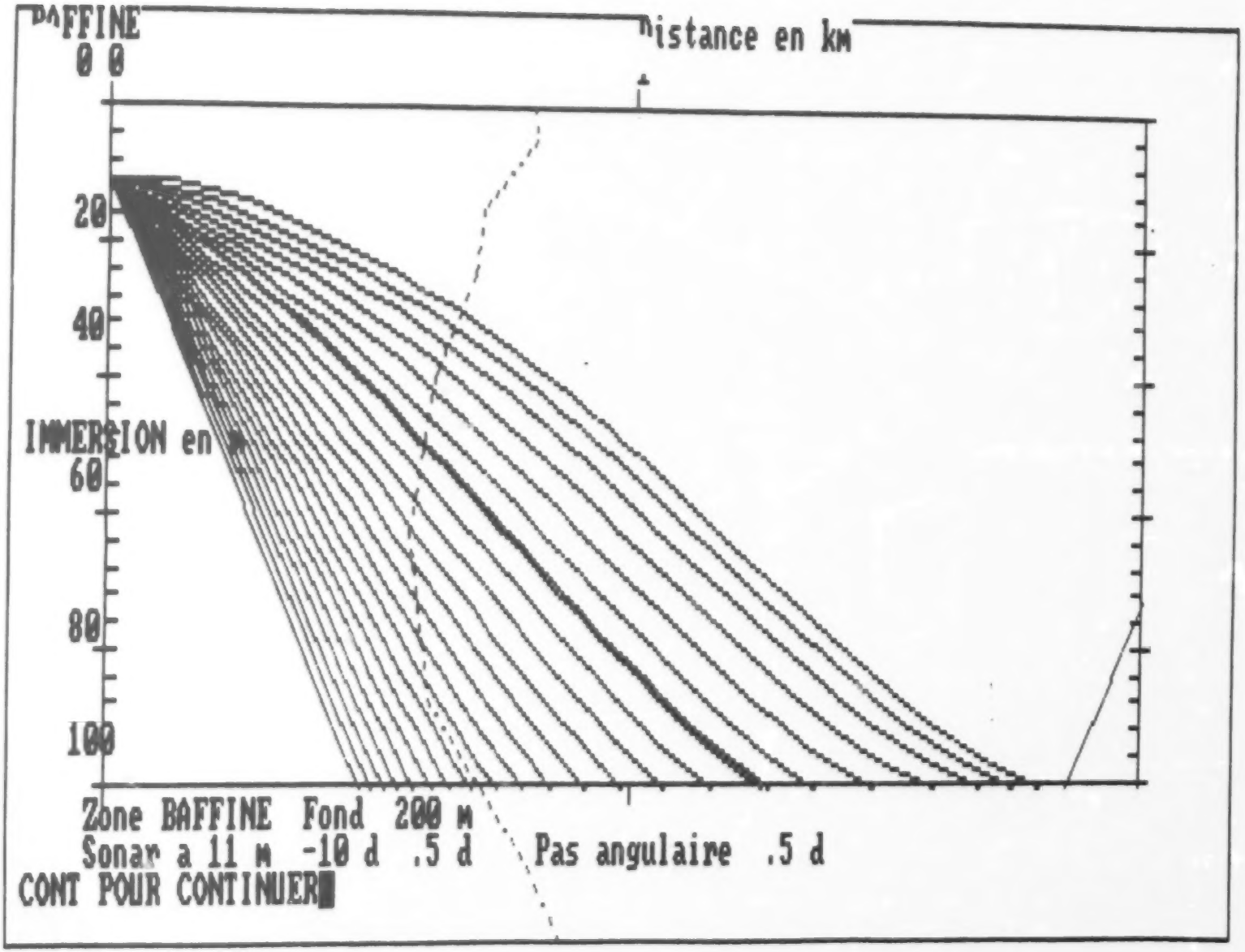
(This profile has been generated from historic records)

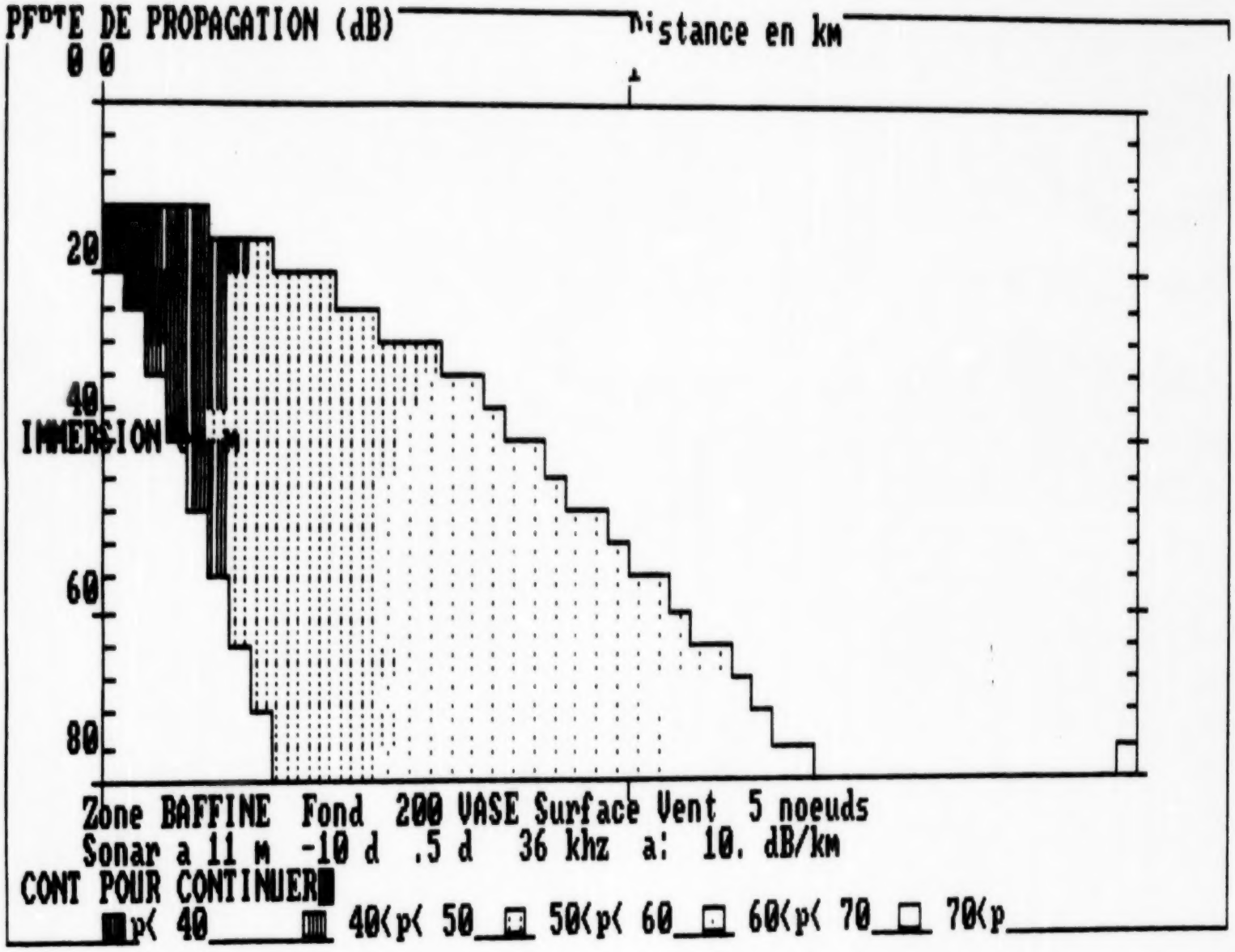
```
^AFFINE
 n   Imm.(m)   Cel.(m/s)   Temp.( C)
 1      0       1445.732      -.8
 2      5       1445.814      -.8
 3     15       1443.625     -1.3
 4     25       1443.315     -1.4
 5     40       1441.656     -1.8
 6   62.5       1440.584     -2.1
 7   87.5       1441.478       -2
 8    112       1445.703     -1.2
 9    137       1448.929      -.6
10    162       1452.574  Immersion en m
11    187       1456.617        .9
12    200       1456.832        .9
```

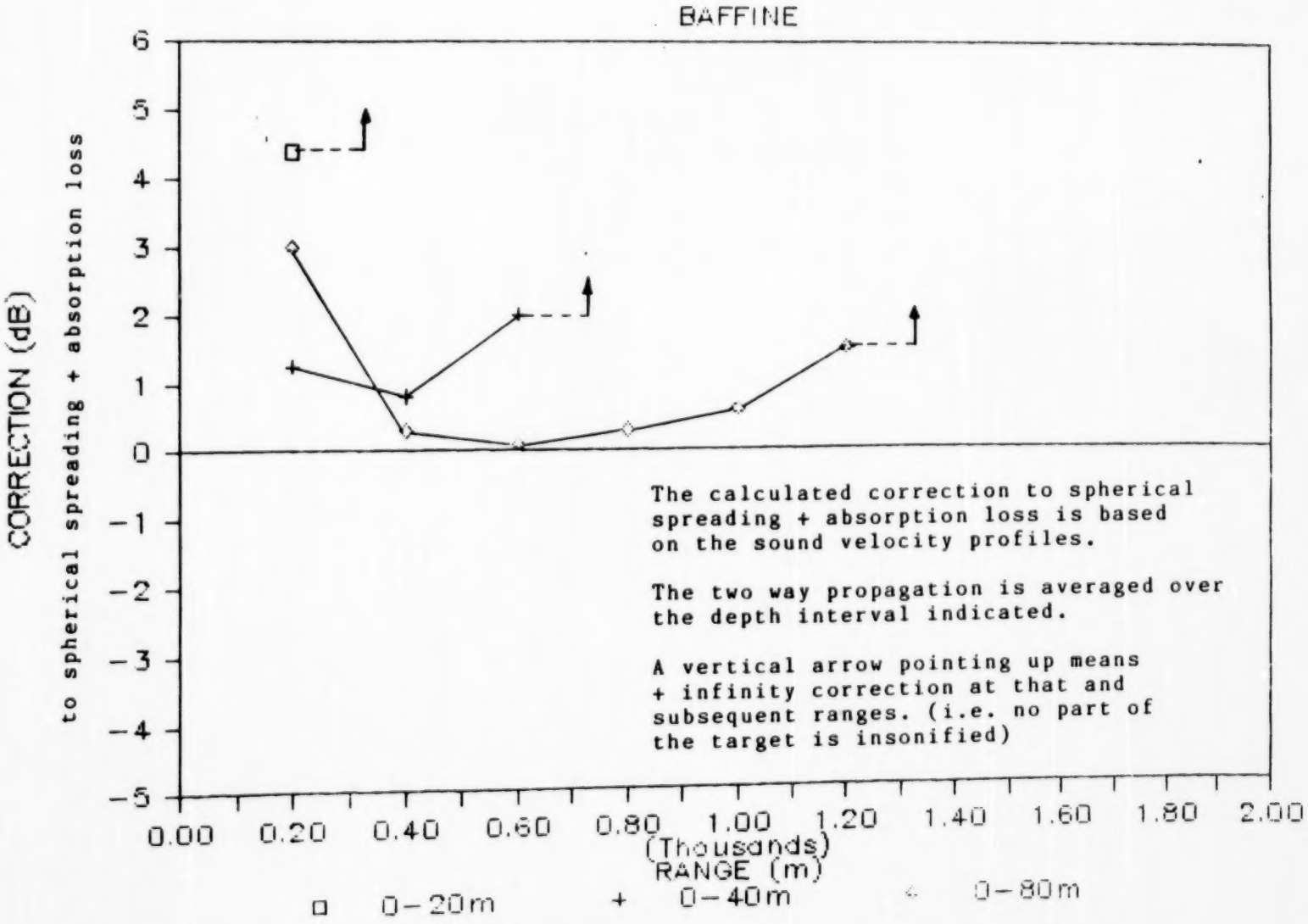


Bathy correct ? _

Voulez-vous un autre trace de la perte avec un nouveau sondage ? N


BAFFINE
0 0
istance en km
20
40
IMMERSION en m
60
80
100
Zone BAFFINE Fond 200 m
Sonar a 11 m -10 d .5 d
Pas angulaire .5 d
CONT POUR CONTINUER


PERTE DE PROPAGATION (dB)
Distance en km
0 0
20
40
IMMERSION
60
80
Zone BAFFINE Fond 200 VASE Surface Vent 5 noeuds
Sonar a 11 m -10 d .5 d 36 khz a: 10. dB/km
CONT POUR CONTINUER
p(40
40(p(50
50(p(60
60(p(70
70(p


BAFFINE
CORRECTION (dB)
to spherical spreading + absorption loss
6
5
4
3
2
1
0
−1
−2
−3
−4
−5
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
(Thousands)
RANGE (m)
The calculated correction to spherical spreading + absorption loss is based on the sound velocity profiles.
The two way propagation is averaged over the depth interval indicated.
A vertical arrow pointing up means + infinity correction at that and subsequent ranges. (i.e. no part of the target is insonified)
□ 0−20m
+ 0−40m
◇ 0−80m